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CONTENTS

Volume XIX, Number 4 October 1981

PLANT GROWTH FRONTIERS

PLANT GROWTH FRONTIERS 3
Gordon Donald and Michael Whiteman

NEW ROADS TO NITROGEN FIXATION 4
Marcus Franda

BETTER WAYS TO FIX NITROGEN 12
Kenneth A. Kovaly

NEW CHEMICALS PROMISE LARGER CROPS 16
Thomas H. Maugh II

POPULATION TRENDS

POPULATION TRENDS AND PROSPECTS 23
W. Parker Mauldin

MEN AND FAMILY PLANNING 35
Bruce Stokes

PROSPECTS FOR IMPROVED CONTRACEPTION 43
Linda Atkinson, S. Bruce Shearer,
Oscar Harkavy, and Richard Lincoln

SIGNS OF CHANGE IN MORTALITY TRENDS--
IS PROGRESS SLOWING? 54
Davidson R. Gwatkin

CLEAN WATER

WHY A WATER AND SANITATION DECADE? 67
Earthscan

SUPPLYING WATER: MAINTENANCE PROBLEMS
AND COMMUNITY PARTICIPATION 74
Anil Agarwal

SANITATION AND WELL BUILDING 86
S. B. Watt and W. E. Wood

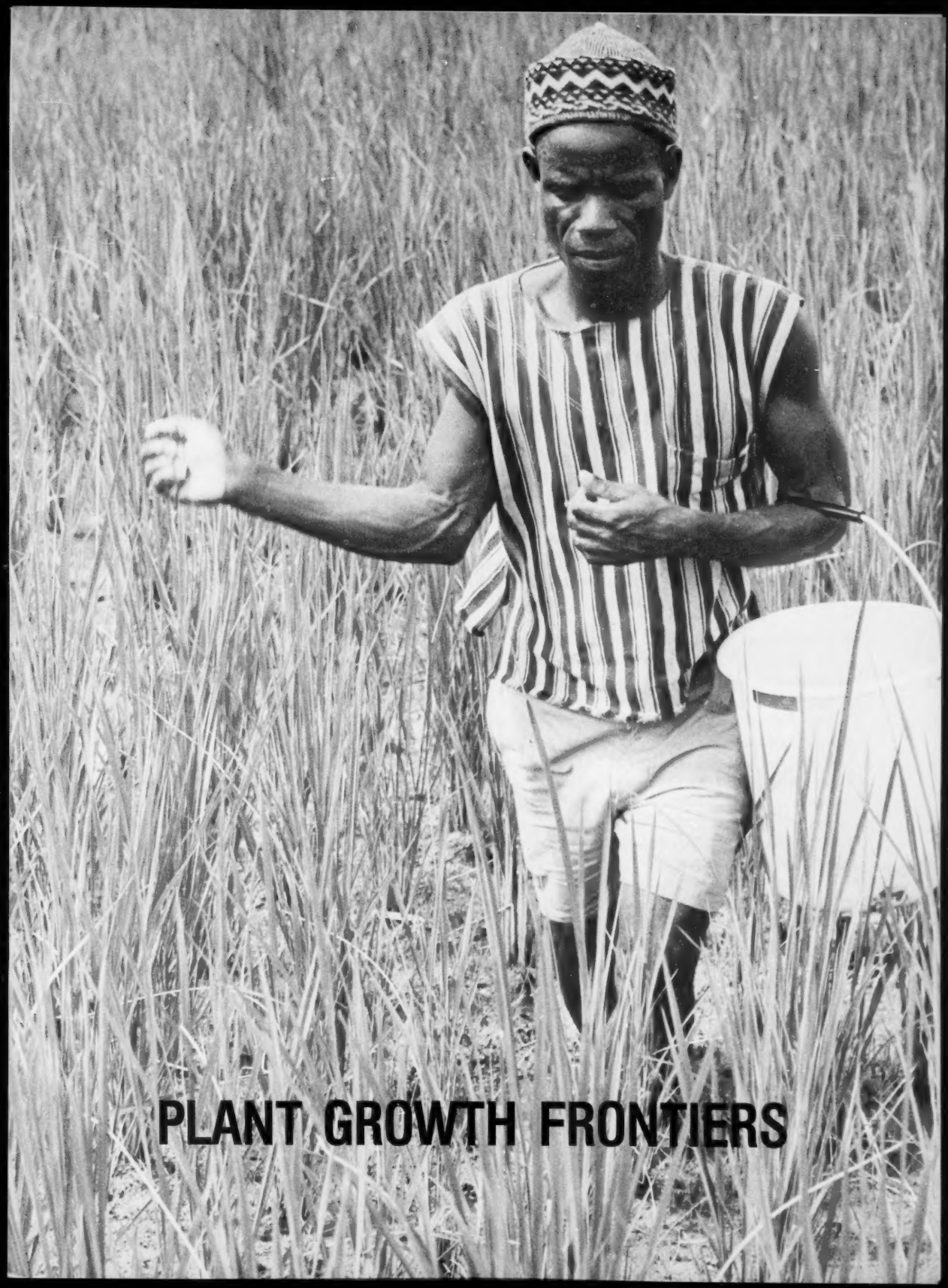
AFRICAN DEVELOPMENT

PERSPECTIVES AND PROBLEMS OF DEVELOPMENT IN SUB-SAHARAN AFRICA 95
Shankar N. Acharya

FOOD PROBLEMS AND PROSPECTS IN SUB-SAHARAN AFRICA 118
U.S. Department of Agriculture

INDEX 133

Money values will be expressed in U.S. dollars unless otherwise specified. The spelling "tonne" will be used to indicate metric tonnes (1000 kilograms), and "ton" will refer to traditional U.K.-U.S. tons (2000 lbs. or 2400 lbs.).



PLANT GROWTH FRONTIERS

LIBERIAN FARMER FERTILIZING RICE ON THE GBEDIN RICE PROJECT, LIBERIA (Photo: FAO, G. Tortoli).

Plant Growth Frontiers

Gordon Donald and Michael Whiteman
Editors of the Development Digest

The following three articles deal with newly developing methods of increasing plant growth. The importance of achieving gains in agricultural crop yields for overall development in Asia--where population presses on land supplies, in Africa--where traditional methods of cultivation can no longer feed the people, and in Latin America--where growing populations and receding settlement frontiers are evident in most areas, cannot be overestimated. Especially in countries which have limited industrial exports, agricultural productivity is a key to overall economic growth as well as to nutritional welfare. Nitrogen plays an essential role in improving agricultural productivity.

Today nitrogen is added to the soil most commonly by applying chemical fertilizers (phosphate and potash fertilizers are not covered here). But the rising cost of natural gas, which has been a necessary input for the present method of manufacturing nitrogen fertilizer, has been seriously raising the price of such fertilizer since 1974. Gas is a non-renewable source and its consumption cannot be expanded indefinitely, while the demand for soil fertility increase is one that looks to be expanding for years to come. So the need to seek other ways of making nitrogen fertilizer that will not depend on fossil fuels is clear. The first two articles consider some alternatives in the manufacturing process.

Nitrogen from the air is "fixed", i.e., changed into a form which can contribute to plant growth and production, in the chemical fertilizer factories. But the fixation process also occurs in nature; biological nitrogen fixation has always been the largest contributor of fertility to the soil, compensating for the removal of nitrogen from it by the growth of trees and plants. This process is beginning to be better understood for purposes of human exploitation. The kind of biological fixation which is best studied is that performed by a genus of microbe called *Rhizobium* which form nodules on the roots of certain legumes (beans, clovers, and others). The activity of these microbes is the basis of much of the soil fertility renewal from crop rotation. This subject was discussed in the *Development Digest* of October 1975, p. 18, and the ways in which this process can be, and in some areas has been, used for farming were described. The two articles that follow here pursue the subject further. They tell of some of the new avenues that scientists are following to increase biological nitrogen fixation by exploring different microbes and different plant hosts, and by using some of the biological creation possibilities emerging from recent research results with recombinant DNA--that is, altering the sequence of the elements in the genetic code of different microbes or plants to obtain new qualities.

The final article takes a different direction in reporting some very recent discoveries of the capabilities of two newly developed chemicals, both of which appear to contribute substantially to plant growth and which may become obtainable at reasonable cost. All of the possibilities discussed here are on the scientific frontier in one way or another, although some are closer than others to reliable applications at reasonable cost.

New Roads to Nitrogen Fixation

Marcus Franda

[This article describes three projects under way in a leading laboratory specializing in nitrogen fertilization: (1) avoiding fossil fuels in the manufacturing process; (2) use of the azolla fern in conjunction with rice growing; (3) developing new nitrogen-fixing microbes.]

Founded in 1930 for the study of chlorophyll and photosynthesis by the inventor Charles Kettering, the Kettering Foundation Laboratory in Yellow Springs, Ohio has attained a leadership position in basic research in this field. In the 1970s it shifted focus somewhat toward specializing in the area of nitrogen fixation.

Current Projects

Nitrogen fertilizer generator. One of the most talked about short-term projects at the Kettering lab is the development of a small nitrogen fertilizer generator, using an old electric arc discharge method that was discovered at the beginning of this century. Essentially, the process requires that air be pumped through an electric arc in such a way that the nitrogen and oxygen in the air combine to make nitric oxides. Through a system of rapid quenching of temperatures, the nitric oxides are made to react rapidly with oxygen in the air to form gases, which are in turn pumped through water to form nitric acids. These acids can then be neutralized by running them over limestone or calcium phosphate, the end product being a form of liquid fertilizer that can be fed directly into irrigation water, sprayed on fields, or stored indefinitely.

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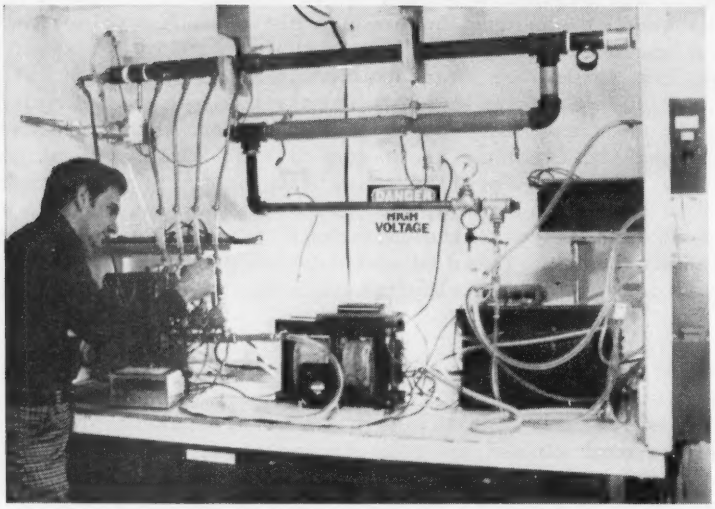
New Hampshire.

Although there is evidence of its use as early as the 1880s, the electric arc discharge method first came to prominent attention in America when it was used to produce nitrogen fertilizer at a plant in Niagara Falls, New York from 1902 to 1904. At about the same time, the Norwegians began constructing several much larger plants powering the electric arc system with inexpensive hydroelectric power. Then the Haber-Bosch process, developed in Germany in 1913, replaced the electric arc method as the world's principal means of producing synthetic fertilizer, although the electric arc method continued to be used in Norway until the 1930s. But today's spiraling costs for natural gas--the principal source of energy used to produce synthetic fertilizer by the Haber-Bosch process--have recently led to a search for alternative methods of producing fixed nitrogen.

R. William Treharne of the Kettering lab has been the major figure involved in the attempt to revive interest in the electric arc method, and he has introduced a number of modifications that might make it more viable now than it was earlier. Instead of large-scale plants like those in Niagara Falls or Norway, Treharne has been experimenting with a small 3-kilowatt system that can produce a ton of fixed nitrogen per 50,000 kilowatt hours. Treharne is hoping to develop a small and simple but efficient system that would enable farmers in isolated areas to produce fertilizer on their own farms with solar, wind, or hydroelectric power, from small, individually owned generators.

A prototype of Treharne's fertilizer generator has been installed on an experimental farm at the University of Nebraska, being powered by a costly photovoltaic solar array longer than a football field. That installation has been producing fertilizer during long intervals of time when the solar array is not being used for irrigation purposes but at the outrageously high cost of $28 per peak watt. Treharne is convinced that solar power is the most expensive way to run the electric system; solar costs would have to come down from their present average of $7-$10 per peak watt to around 50 cents per peak watt to make his system economical.

More promising than solar energy is the possibility of driving the fertilizer generator by wind power. Treharne hopes to work with people from the University of Hawaii to install a wind-driven prototype on the Big Island in either late 1980 or 1981. A third prototype, powered by hydroelectric energy, is scheduled to be installed in Nevada in early 1980. A private contractor has already developed a 3-kilowatt turbine that can be powered by water traveling down from a 400-foot elevation through a pipe 2 inches in diameter.



A prototype of the electric arc fertilizer generator.

The Kettering lab has received a number of inquiries about and requests for prototypes of the arc generator, with most of them coming from Latin America, India, and Nepal. But the Kettering Foundation is determined that it will not release the system for worldwide distribution until it has carried out more experimentation because, as Kettering Trustee Harrison Brown said, "The Third World is littered with great inventions that failed because they were introduced too fast." The appeal of the arc generator to policy-makers in the less-developed countries is understandable. If it works, it could provide a source of nitrogen fertilizer to farmers in the most remote areas, using only water, the wind, or the sun for energy. The only components of a fertilizer unit would be an electric generator, water, a neutralizing agent like limestone, a few tubes and wires, a pump, and the know-how to keep the system functioning. Treharne has developed an enclosed unit that could conceivably be installed, maintained, and replicated in regions where some basic skills do exist in the countryside (in Punjab or Nepal, for example). Particularly in remote areas where electricity and fertilizer are not available but there is an abundance of hydropower, the electric arc generator could be of great importance in the future.

Kettering is carrying out a number of tests of the endurance and wear on some of the components of their basic three-kilowatt system--especially the electrode, the air pump and several small electrical motors. They are also trying to find ways to use some of the waste heat that now constitutes the major inefficiency of the arc process. Finally, they are trying to find more efficient ways to collect the nitrogen acids and convert them to calcium nitrate and phosphoric acid, the ultimate goal being to produce a ton of fixed nitrogen in the form of usable fertilizer per 25,000 kilowatt hours of electricity, as compared with a ton for every 50,000 kilowatt hours at present.

At this point in the development of the electric arc process, it would appear to be of greatest potential benefit in Asia to the wealthier farmers. The cheapest system that Treharne has developed thus far is a laboratory model, a 3-kilowatt enclosed hydro unit that costs $4,000 for the hydro generator and $900 for the arc generator. Treharne estimates that such a unit could produce enough fertilizer for 20-25 acres of land at present rates of application on South Asia's most progressive farms. This might make the unit quite attractive to those farmers who now own that much land, but 20-25 acres in Asia is a large holding. Experiments with cooperative use by smaller farmers of new inventions have not been very successful. Even if a poor farmer in Asia could find a way to acquire one of Treharne's 3-kilowatt units, the system takes up at least a small room and requires for efficient operation some minimal understanding of mechanics and electricity. [Comment: Village-sized projects need not be ruled out for all of the Third World.]

The Azolla fern. The Kettering project that is most likely to provide benefits to poorer farmers in South Asia in the short run is experimentation with the small fresh-water fern Azolla, being conducted by Gerald Peters and his associates. A single Azolla plant grows no more than one-quarter inch high at full maturity, but some species of the tiny ferns layer themselves on top of one another to reach a possible combined height of an inch or two. Nitrogen is fixed by a blue-green algae that is always found inside cavities of the Azolla fronds. Wherever you have Azolla, you have an assured source of nitrogen fertilizer. There are also a number of free-living blue-green algae, but such algae are not as good at fixing nitrogen in their free-living state as those found inside the Azolla fern. The Chinese have known about Azolla for hundreds of years and have cultivated it in tanks and greenhouses over the winter months, for use on paddy fields in the spring. Depending on species, the plant grows in almost any wet place and in a wide range of climates. In most countries--America included--it is considered a weed.

Peters has obtained and identified four of the five, possibly six known species of Azolla. He is attempting to understand how the

plant functions, how to optimize its biomass production, and how to increase the efficiency of the blue-green algae in fixing nitrogen. Other scientists in Belgium, the Netherlands, England, China, the Philippines, and India are also doing basic research and field studies with Azolla in the attempt to make it even more viable as a fertilizer crop plant. Extensive field trials are being conducted at the University of California's Davis campus and at the International Rice Research Institute (IRRI) in the Philippines.

Centuries of experience in China, Vietnam, and Nepal have demonstrated that increases in rice yield can be achieved by simply growing Azolla as a green manure during the fallow season. Azolla has the advantage that it adds carbon, other minerals, and nutrients to the soil--thus acting as a source of humus and a soil conditioner--an advantage that is not present with chemical fertilizers. Unlike many other plants, Azolla also breaks down very quickly, which means that the nitrogen is almost immediately available as a biological fertilizer once the Azolla is plowed under or killed. The greatest gains in rice production using Azolla have come in field trials in Davis and at IRRI in the Philippines, where the fern has been systematically grown in various combinations on the surface of the water between rows of rice plants, buried beneath the soil and re-sown at several points during the growing season, and occasionally used as green manure during the fallow season as well. Under these circumstances, Azolla has been found to prohibit weed growth in the rice field, provide significant amounts of nitrogen and other nutrients to the soil, and increase crop yields considerably when compared to an unfertilized control plot.

The importance of Azolla is that it can provide a bountiful source of nitrogen biofertilizer to any cultivator who has wet land, without his having to purchase and transport fertilizer. Since the plant multiplies, weed-like, very rapidly, it can already be of great value to any rice farmer who has access to a few parent plants. Throughout the world, Azolla plants are readily available, free of charge. Indeed, much of the scum-like green material commonly seen on stagnant water ponds throughout Asia is Azolla, or free-living blue-green algae. Should farmers ever be able to adopt some of the more sophisticated Azolla and rice crop rotations and interplantings being tried at Davis and in the Philippines, increases in rice production could conceivably equal those for fields where chemical fertilizers have been used.

Peters' work is significant because he could: (a) identify the best species and varieties of Azolla for a given environment; (b) help work out management techniques; and (c) eventually breed new varieties. Peters discovered in 1974 that it is the blue-green algae, and not the fern, that actually fixes nitrogen. He has since found that the algae does not keep growing forever but instead goes into what he calls a

"metabolic idling" and quits dividing once it has filled the cavity of the Azolla fern. In his attempts to maximize the nitrogen-fixing potential of the symbiosis, Peters is now trying to find out more about the functioning of the enzyme within the blue-green algae and the interaction between the algae and the fern. He also talks about the possibility of creating more ideal plants by hybridization, and of discoveries that might make it possible to desiccate Azolla spores. The ability to desiccate spores would gain for man the capability of multiplying them at incredibly rapid rates and storing them with unprecedented ease.

A pond of the Azolla fern growing in Mainland China (Photo credit: Gerald Peters).

Finally, Peters would like to find a herbicide that would selectively kill Azolla without affecting rice plants. If this could be done, the Azolla could be selectively killed several times during a growing season without having to use large amounts of manual labor. The difficulties involved in using manual labor to kill and re-sow Azolla are, first, that it is expensive for this purpose, even in low-wage Asia, and second, its use results in damage to the roots of rice plants. The more often Azolla plants can be brought to full cover and killed during a growing season, the more nitrogen is fixed in the soil. If an inexpensive Azolla herbicide could be developed that would not

disturb the roots of rice plants, its impact on the lives of poor rice farmers throughout the world would be widespread.

Other nitrogen-fixing microbes. A third Kettering project that would appear to have important pay-offs in the not-too-distant future is the experimentation being carried out by Maurice Lalonde and his associates with alder and other nonleguminous nitrogen-fixing plants. Less than two years ago, at Harvard University, a group of scientists were able to isolate an unusual fungus-like microbe, now given the species name *Frankia*, which had been known for years as a nitrogen-fixing microorganism that would infect a group of specific non-legumes, in the way that *Rhizobia* infect legumes. The discovery at Harvard has made it possible to grow *Frankia* in culture, out of the nodules of plants, and, therefore, to simplify laboratory experiments. Lalonde's experimentation is designed to reveal more about the functioning of *Frankia* and the symbiosis between them and the plants with which they associate.

Lalonde is particularly concerned with growing trees. His lab is filled with young alder trees and other nonlegumes no more than a few inches high, growing in plastic bags and in growth chambers that look like refrigerators, all the while being examined down to their smallest particle by the most sophisticated electronic machines and microscopes. Alder is particularly important because its 23 species grow all over the world, in climates ranging from the tropics to the coldest parts of Canada, and it has an enormous number of possible uses. In the Soviet Union, the leaves of some species of alder are used as cattle feed--in fact, Soviet cattle prefer the leaves of alder bushes to other foods. Other species are especially fast-growing trees that are of great potential for biomass production. Still others can be reduced to sugars and then used as food or fuel.

Some of the microbes that Lalonde has isolated with his new culture techniques were used to inoculate 86,000 plants across Canada. Others will be tried on large plantings in Senegal in 1980. Lalonde is enthusiastic about the possible applications of his research in the future. The nonleguminous trees that can be "turned on" by *Frankia* include casuarina, coriaria (a New Zealand type of pine), Russian olive, and a host of others. In South America, nitrogen-fixing trees have been planted next to fields of corn, both to provide windbreaks and to furnish nitrogen to the soil. In this case, nitrogen is fixed in the leaves, which can be stored and composted to provide a most valuable source of nitrogen fertilizer.

Selection of the best trees or other plants for any given situation is being studied at various experiment stations. Lalonde's concern, however, is not so much with the plants themselves as with 200 different strains of microbes that can "turn them on." Lalonde has

found that some microbes infect a tree more quickly than others, and that "some strains are sloppy--they do not want to do their job well." Others, he says, "just sit there and do nothing at all." Lalonde and his associates are trying to find out which strains work best with which plants, so that field experimenters can be certain that if they develop an excellent nitrogen-fixing tree they will have an efficient microbe to use in association with it. Lalonde is especially anxious to find the right microbe for *Alnus glutinosa*, a tree that grows from Russia to Spain and produces a lot of wood fiber and wood very quickly. Field experimenters at Iowa State are exploring the possibility of introducing *Alnus glutinosa* into the United States on a large scale.

Lalonde has also been corresponding with scientists in India, who have become interested in using the casuarina tree in large-scale plantings. At present, the most widely used tree for large-scale plantings in India is the fast-growing eucalyptus, which does not fix nitrogen in the soil but instead removes it. As Lalonde points out, the casuarina grows all over India and will enrich the soil because of its nitrogen-fixing properties. He is convinced that it will grow as fast as eucalyptus if the right types are selected and the right microbes are used in association with them. The plantings that Lalonde is recommending for Senegal are what he calls "mixed culture," consisting of rows of casuarina interspersed with rows of eucalyptus and other trees. Such mixed cultures make it possible to provide to the soil different nutrients from different trees and also tend to produce plants that are more disease-resistant than those grown in monocultural situations.

In the long run, Lalonde is hopeful that he and other scientists might find ways to sporulate the microbes that infect nonleguminous nitrogen-fixing plants, so they could be more easily stored over long periods of time. He would also like to explore possibilities for translocating nitrogen from one plant to another through "bridges" of microbes in the soil, in such a manner that nitrogen could be transferred from the roots of nitrogen-fixing plants to the roots of non-nitrogen fixers. To accomplish this, he would have to find precisely the right microbe to infect precisely the right combination of plants, a most difficult task when one considers the millions of microbes and plants in the world.

[Extracted from Kettering's Nitrogen Fixers Part III, pp. 5-9. Report No. 15, General. Copyright© 1980, American Universities Field Staff, Hanover, New Hampshire.]

Better Ways to Fix Nitrogen

Kenneth A. Kovaly

[This article begins by describing the principal method used to make chemical nitrogen fertilizer. It then tells of some new alternative ways to reach the same result that are being explored: one is to create new types of bacteria by genetic engineering; another is to eliminate the need for gas or oil in the usual manufacturing process by using new chemicals; a more distant idea is to introduce nitrogen-fixing capability into common food plants.]

The Haber-Bosch process used in the hundreds of plants that make up the worldwide ammonia industry got its start in Germany in 1913. The inventors gave the government just what it needed for World War I--freedom from imported nitrates for explosives. Today this process is the basis for the giant nitrogen-fixation industry, which currently "fixes" gaseous nitrogen from the air into about 80 million metric tons of ammonia per year. Three-fourths of the ammonia goes into nitrogen fertilizers to help grow crops to feed the world. The rest goes into plastics, nylon fibers, animal feed materials, a host of industrial chemicals, as well as civilian and military explosives.

The Haber-Bosch process has been improved and adapted to new raw materials and energy sources. Its plants have been engineered and automated to a high degree of efficiency and are now built on an enormous scale. But the process remains basically the same one the two Nobel prize winners invented on the eve of World War I. Only now is competition for improvement in this venerable process on the way. Gradually--or perhaps suddenly--the huge existing ammonia industry could become obsolete.

Mr. Kovaly is President of Technical Insights, Inc., a publishing firm in Fort Lee, New Jersey.

Haber-Bosch ammonia plants get their nitrogen--which makes up 82% of ammonia--from the air. It is free. It is the only item that is. Natural gas or petroleum naphtha are usually used for the high temperatures and pressures (sometimes 1,000 atmospheres) needed to make nitrogen and hydrogen combine in the presence of a catalyst to make ammonia. These hydrocarbon feedstocks--reacting with steam--are also the source of hydrogen.

Coal has been used in the past and will be again, but coal-based plants require much higher capital investments and have not been economic for many years in most locations. Burgeoning fuel costs have run production costs for ammonia up tremendously since 1974, as has the price of new plants. The high pressures and temperatures needed demand a great deal of expensive, specialized heavy equipment. The price tag on a 1,000-ton-per-day ammonia plant--and few companies think anything smaller is economical--is over $75 million.

Bacterial Factories

Long before rising costs of fuel and equipment hit the ammonia industry, chemists had known that there is a better way to fix nitrogen--quietly, at atmospheric pressures and normal temperatures. Certain microorganisms do this. They live free in the soil or in nodules on the roots of legume plants like clover, soybeans, alfalfa, or peas. Before man built the synthetic nitrogen-fixation industry this biological process was the chief source of the fixed nitrogen needed for plant life, and hence animal life. Fixed nitrogen in the form of ammonia or other nitrogen compounds is needed to make amino acids, which make up proteins, the basic building material of all living cells. Attempts to unravel the natural process have been made for many years. Only recently have biochemists come close to understanding the process.

Biochemists now have learned that the natural nitrogen-fixing process uses an enzyme, nitrogenase, to catalyze the reaction between nitrogen from the air and hydrogen from water to form ammonia within bacterial cells. The structure of the nitrogenase is a protein of high molecular weight. A cofactor, an additional molecule, is required for the catalytic activity of nitrogenase. Its structure has not been worked out completely, but it does contain molybdenum, iron, and sulfur. The active site of the catalytic reaction is probably at the portion of the molecule containing these elements. At this site nitrogen and hydrogen atoms are positioned in such a way that the energy needed for the combination is supplied to them and they can react. The source of the energy is the oxidation of carbohydrates by bacteria. The carbohydrates are produced by photosynthesis in green plants.

Genetic Engineering

At present the only practical way to make use of the natural biological nitrogen-fixation process is one that has been used since ancient times--rotating legume crops with other crops to enrich the soil. However, recent discoveries make it possible to do more than this in the laboratory. Nitrogen from air bubbled through a liquid medium in which bacteria are growing can be fixed so that the bacteria grow with no other source of nitrogen. Nitrogenase enzyme can also be extracted from living bacteria and made to fix nitrogen in laboratory glassware. These processes are too slow to be commercial yet, although improvements are coming rapidly. Use of recombinant DNA and other techniques of "genetic engineering" have already made it possible to transfer the capability to fix nitrogen from slow-growing bacteria to common bacteria that grow rapidly under artificial conditions. The same techniques have also made it possible for bacteria to convert nitrogen into ammonia that can be collected, rather than into amino acids.

Further development of these techniques could turn the present nitrogen-fixation industry upside down. One possibility is the development of factories similar to fermentation facilities. In these factories bacteria would grow in large tanks and receive their nitrogen from air bubbled through the liquid culture medium. The by-products of paper mills or other wastes could be used as carbohydrate energy sources for large industrial installations. Bacterial mass could be removed as a sludge that would serve as a rich organic fertilizer. Instead of industrial installations, small units could be set up on individual farms and use crop residues or animal manure as nutrients for bacteria.

Nitrogen-fixing microorganisms might also be grown in tanks to produce ammonia instead of an organic fertilizer. Or nitrogenase could be extracted and produce ammonia directly.

Genetic engineering may also be able to produce nitrogen-fixing microorganisms that will fix nitrogen in the soil much more efficiently than wild strains. These bacteria could be introduced into the soil so that the nitrogen needed by crop plants is produced where it is needed. Other strains might be produced that would grow cooperatively with crops such as corn in much the same way that natural nitrogen-fixing bacteria now grow in root nodules of legumes.

Synthesizing Nitrogenase

Understanding the nitrogenase structure has given some good leads to synthetic organic chemists who have been faced with heavy going in their search for catalysts which would fix nitrogen at normal tempera-

tures and pressures. Compounds have been synthesized which contain molybdenum, iron, and sulfur and may be similar to the active site in the nitrogenase enzyme. So far yields are very low. But if the chemists are on the right track, an industrial process requiring less capital investment and less energy could become a reality. Even more exciting is recent work on entirely unrelated catalysts able to synthesize minute amounts of ammonia from air and water in the presence of sunlight--the sole source of energy.

Commercialization of any of these new ammonia processes could lead to an entirely new structure for the fixed-nitrogen industry. Eliminating the need for natural gas or petroleum fractions could mean that many present locations for ammonia plants--such as those on the U.S. Gulf Coast--would lose their advantages. It is likely that a new process could operate economically on a smaller scale than the existing process. A larger number of smaller plants closer to markets would result, and cause a big shift in the present distribution system. Farm-based units would eliminate the distribution system entirely. A solar process would also mean a big change in the geographical locations of ammonia plants.

The breakthrough that would have the most drastic effect of all may be further away, but is the goal of a number of top-notch research groups that are now working on it. This is the application of genetic engineering to transfer nitrogen-fixation capability from bacteria directly to crop plants. Corn or other crops could then fix their own nitrogen, eliminating the need for nitrogen fertilizers altogether. This would wipe out three-fourths of the existing ammonia industry.

[Extracted from Technology Tomorrow, Vol. 2 No. 5, October 1979, pp. 6-7.
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New Chemicals Promise Larger Crops

Thomas H. Maugh II

[This article describes work on two new chemicals, very recently developed, that promise to be of value for stimulating plant growth. They have not yet been widely tested nor officially approved for sale, however.]

A new generation of plant growth regulators may soon exercise a strong influence on agricultural practices. Unlike earlier generations, which have already proved valuable for such diverse uses as inducing root growth, thinning fruit on trees, regulating crop maturation, aiding harvesting, and increasing the hardiness of plants, the new agents show promise of increasing crop yields and biomass for vegetables, cereal grains, and other produce. The prototypes of this new generation are brassinolide and triacontanol, both of which produce significant increases in crop yields. In recent months, scientists at the U.S. Department of Agriculture (USDA) have synthesized and tested two analogs of brassinolide that are inexpensive enough to use commercially, and that appear to be equally effective. Another scientist, meanwhile, seems to have discovered why results with triacontanol have often been inconsistent.

Brassinolide was discovered in a screening program for new plant hormones initiated at USDA's Beltsville Agricultural Center more than 10 years ago by John W. Mitchell. Mitchell, since retired, began screening pollens because he thought they would have a high concentration of hormones. The USDA group screened

Dr. Maugh is on the staff of Science magazine, The American Association for the Advancement of Science, Washington, D.C.

pollen from nearly 60 species and found that about half caused increased growth in bean seedlings. The greatest growth increases were obtained with pollen from alder trees and from rape (*Brassica napus* L.), a forage crop whose seeds yield an oil used as a lubricant and as a food. These two pollens shared an unusual characteristic. When an extract of the pollens was applied at high concentrations, the stem of the seedlings would split above the second pair of leaves because of the rapid growth, and then grow back together. No other compound has been found that produces this effect. The initial results also showed that the active substance was present in the pollen at a concentration of only parts per billion; most hormones are found at parts-per-million concentrations in plants.

Split internodes

If too high a concentration of brassinolide is applied, the stem of a seedling splits above the second pair of leaves, then grow back together. [Source: N. B. Mandava]

Because this discovery was so promising, a Beltsville team headed by N. Bhushan Mandava undertook a crash program to isolate the active substance from rape pollen, which was more readily available than alder pollen. Michael Kozempel and his colleagues constructed a pilot plant for extracting large amounts of rape pollen with 2-propanol. From 225 kilograms of pollen, the USDA team obtained barely 10 milligrams of a pure, crystalline material that they named brassinolide.

On the basis of spectrometric studies in several laboratories, the group reported in 1979 that brassinolide is a steroid. It is the

first plant growth regulator that has been found to have a steroidal structure. (Steroid is a molecular classification that includes sex and gland hormones, among other substances.) Application of pure brassinolide to bean seedlings produced significant increases in plant growth at concentrations of only 1 nonogram (10^{-9} or one billionth of a gram) per plant and caused splitting of the stem at concentrations of 10 nanograms per plant.

Because isolation or synthesis of brassinolide itself was obviously too expensive for any widespread use on crops, Mandava and Malcolm J. Thompson of Beltsville synthesized several analogs of the chemical to determine which parts of the molecule are most important for activity. Last year, Mandava and Thompson synthesized two analogs--called brassinosteroids--and subjected them to field and hothouse trials.

Mandava reported at a 1981 meeting of the American Chemical Society that the synthetic brassinosteroids promote growth in the same manner as brassinolide, but that four to ten times as much of the synthetic compounds must be used. Even so, the total amount is still very small--only nanograms per plant. When applied to very young plants in field tests conducted by the Beltsville team, the brassinosteroids boosted the harvest of radishes and lettuce by 15 and 30 percent, respectively. Yields of bean and pepper plants in the field were increased by 6 to 7 percent, and that of potatoes in a small trial by about 25 percent. In greenhouse studies, treated bean and pepper plants weighed 35 percent more than untreated plants and produced a bean crop weighing 32 percent more than untreated plants. Field tests are now being conducted on potatoes in Colorado, and tests are planned for this year at several locations on vegetables, soybeans, and other major crops. Among other things, these trials are designed to determine the best time and method for applying the regulators.

Mandava estimates that 1 gram of either synthetic brassinosteroid would cost between $5 and $10 to produce on a commercial scale. That cost is not unreasonable since a gram would cover as much as 2 hectares. The two Beltsville scientists are now undertaking the synthesis of brassinolide and one other analog using Chesapeake Bay oysters, which provide a relatively cheap and abundant supply of steroids as a starting material.

Meanwhile, John Siddal of the Zoecon Corporation in Palo Alto and Steven Fung, now with Ayerst Pharmaceuticals in Montreal, revealed that they have synthesized brassinolide. The same feat has also been accomplished by scientists at the Tokyo Institute of Technology. Synthetic brassinolide is too expensive for use on field crops, Siddal says, but Zoecon thinks it might prove useful for certain specialized crops and for applications in biochemical research.

Brassinolide and the brassinosteroids are not without some potential problems that require further research. Because they are steroids, it is possible that they could have some undesirable effects on insects, wildlife, and perhaps even man--although Mandava is quick to point out that no indication of such effects has been observed. Furthermore, because of the high value of vegetable and other crops on which the chemicals could be used, farmers may be reluctant to try them until their value has been thoroughly proved.

Triacontanol. Prior to some current research by Andrew J. Welebir of Biochemical Research Corporation in Falls Church, Virginia, triacontanol's history has had several ups and downs. It was discovered in the mid-1970s by Stanley K. Ries of Michigan State University, who observed that placing chopped alfalfa in fields significantly increased the yield of tomatoes and other crops. When he isolated the active ingredient in 1977, he found that it was triacontanol, a constituent of beeswax and a variety of plants observed as long ago as 1934. In his initial studies, Ries reported that triacontanol produced increases of 8 to 63 percent in yields of navy beans, asparagus, sweet corn, carrots, cucumbers, radishes, and tomatoes. The growth increases were rapid and, in some cases, even occurred in the dark.

Subsequent field tests of triacontanol by Ries and by USDA, universities and chemical companies proved disappointing, however. Sometimes the chemical would produce a substantially increased yield, and sometimes nothing would happen. Many investigators gave up on the compound because it proved so unreliable. Ries attributes most of these problems to the method of formulation of triacontanol. The long-chain alcohol is very insoluable in water, and Ries and others have used detergents and surfactants to emulsify it and keep it in solution. Clearly this has not been adequate, since the inconsistent results have continued. Ries himself is discouraged and says he will work on the problem in the field for only one more season. If he has not achieved satisfactory results by then, he says, he will drop field research on triacontanol and go on to other projects.

Welebir, however, thinks that formulation is only part of the problem. Investigating the interactions of triacontanol with plant hormones, he observed that the activity of triacontanol is very sensitive to the concentration of metal ions, particularly calcium and lanthanum. He has also found that plant response occurs only when the *p*H of the triacontanol solution is 8 or greater. He presented some of the results of this research at an American Chemical Society meeting in March, 1981.

Even before he developed a theoretical basis for their use, however, Welebir began adding calcium or lanthanum salts to preparations of triacontanol and found not only that the regulator worked consis-

tently, but also that he obtained better results than other investigators. He suggests that the detergents and surfactants used to emulsify the triacontanol were inhibiting the plant stimulation by their effect on calcium. He now uses a preparation of triacontanol dissolved in acetone and water; the concentration can be quite low, since it is effective when applied at a rate of 10 milligrams per acre. The cost is 2 to 4 cents per acre.

In preliminary field trials conducted last summer, Welebir found that the new formulation increased the weight of fresh sweet corn by 51 to 54 percent in three separate trials. Application to seedlings produced a 6 to 19 percent increase in ear length due to the formation of larger kernels, and an increase of 20 percent in the number of ears. Field tests with tomatoes, Welebir says, showed early increases in yields of 65 to 72 percent, while the yield of beans increased by as much as 90 percent. Preliminary results with field corn, which had shown no effects in earlier studies with triacontanol, suggest that a 15 to 20 percent increase in yield can be obtained. Many new field trials on a variety of major crops will be conducted during the coming growing season to see if the results remain consistent.

Both the brassinosteroids and triacontanol will, of course, have to be approved by the Environmental Protection Agency (EPA) before they can be used on a commercial basis in the United States. Welebir, for one, sees little problem with this, since "triacontanol is ubiquitous in nature; corn tissue contains about 235 micrograms per gram, compared to the low nanogram levels each plant receives." Brassinolide also appears to be present in a large number of species. These new growth promoters, and others like them that seem certain to follow, should prove very valuable to agriculture.

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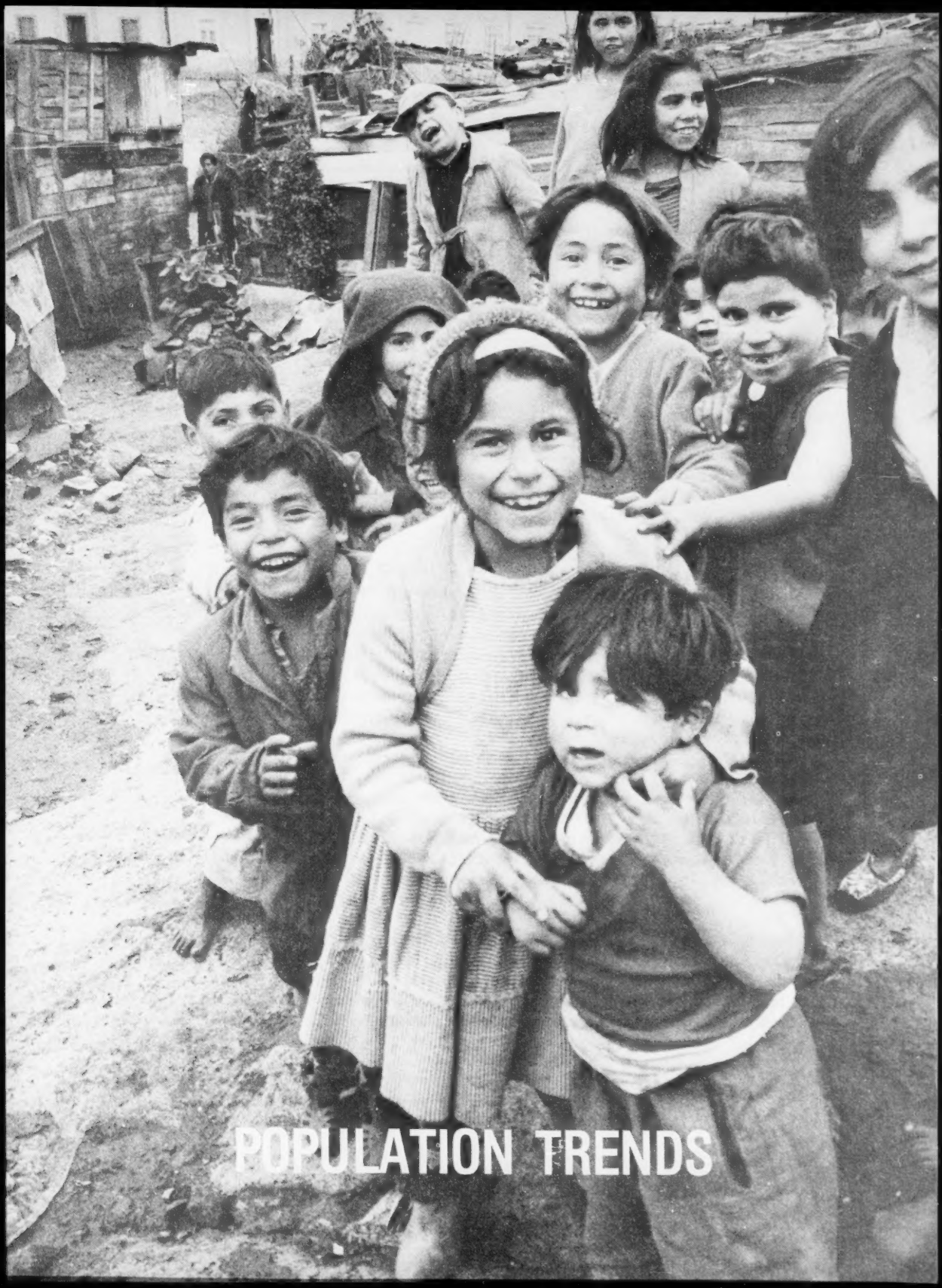

POPULATION TRENDS

CHILEAN CHILDREN
(Photo: WHO, Paul Almasy)

Population Trends and Prospects

W. Parker Mauldin

[For the next 20 years there is likely to be a slowing of population growth rates for all areas of the world except Africa. The present population of developed countries is expected to increase by about 12 percent by the year 2000; that of developing countries is expected to increase by about 50 percent. The momentum of population growth is strong; a few analysts suggest that world growth may cease at 8 billion, but a figure of more than 10 billion seems much more likely.]

The population of the world increased by 75 percent in the past 30 years, from 2.5 billion in 1950 to 4.4 billion in 1980. In 1950, one-third of the population lived in developed countries--Europe, Northern America, the Soviet Union, Japan, and Australia--and two-thirds lived in developing countries. The increase during this period was quite small in Europe, an increase of 23 percent. The United States and the Soviet Union grew at slightly less than 50 percent. The developing countries grew much more, both in numbers and rates; their populations almost doubled, increasing from 1.7 to 3.3 billion. The change was most rapid in Latin America with an increase of 125 percent, from 164 million to 368 million. Africa also more than doubled its population, from 219 million to 469 million (+114 percent). In 1950 the population of Asia numbered almost 1.4 billion, and today it is 2.6 billion, an increase of 85 percent.

The prospects until the year 2000 are for a slowing of growth rates for all areas except Africa, but the numbers to be added will be enormous. Population projections of the United Nations anticipate a rapid slowing of population growth in the developed countries, an increase

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of less than 8 percent in Europe, about 17 percent in the United States and the Soviet Union, and about 12.5 percent for all developed countries. The less developed countries are likely to increase their population by one-half: Africa 76 percent, Latin America 65 percent, South Asia 55 percent and East Asia 24 percent. Thus, half a century's growth may well show an increase in the population of developed countries of just over one-half the 1950 numbers, from 832 to 1,272 million. In the developing countries the increase will be far greater, from 1.7 to 4.9 billion.

Adequacy of Data

There is much that we do not know about the world's population size and growth. Our best estimate is that the population of the world is about 4.5 billion, but that figure could be in error by 200 million--and is likely to be too low rather than too high. We cannot be sure, for example, that China's population is within the range of 950 to 1,000 million (its census in 1982 will give a more reliable figure), or that Nigeria's population is within the range 70 to 85 million. Even in the United States the net undercount of the census is about 5 to 7 million, and for the most part the census figure is used although a larger figure is known to be more nearly correct. Fertility and mortality rates are particularly deficient for Black Africa, and for many countries we do not know whether fertility rates are going up or down--or, more likely, are changing hardly at all. Knowledge about mortality rates is in some respects even more deficient, and again, particularly for Black Africa. Despite the lack of precise information, however, a great deal is known about population size and growth and about mortality and fertility trends. There have been major improvements during the past 15 years or so in the collection of data, both through censuses and sample surveys, and in analytical techniques. For convenience, and with no great loss in accuracy, for the most part I shall use the United Nations' projected figures for 1980 to describe current levels.

Mortality

The very large increase in population during the past several decades is primarily the consequence of a very rapid decline in mortality throughout the world. With today's population we would have more than 80 million deaths a year if 1950 mortality rates were unchanged, instead of fewer than 50 million that result from today's population and mortality rates. In 1950, life expectancy at birth was about 65 years in developed countries, and perhaps 42.5 years in developing countries. Today it is 7 years more for developed countries, and perhaps 13 years more in developing countries, or about 72 and 55-56 years respectively. The gain has been largest in developing countries, but the gap between the two groups of countries remains very large.

Mortality rates are highest in Africa, particularly Black Africa, although life expectancy at birth increased by 12 years, from about 38 in 1950 to almost 50 today, and the crude death rate dropped from almost 27 to 16 per 1,000 per year. Infant mortality remains very, very high, perhaps 200 or more per 1,000 per year in Black Africa and about 150 in North Africa. The figures for South Asia are comparable. Life expectancy was just under 40 years in 1950, and today is about 53; the crude death rate decreased from about 25 to 13.3. Life expectancy in East Asia is 65 to 66 years, a remarkable increase of 18 years from 47.5 in 1950. Life expectancy in Latin America also registered major gains from 52 to more than 64 years.

The lowest crude death rates, around 5 per 1,000, are found in some of the developing countries such as Taiwan, South Korea, Hong Kong, and Singapore, rather than in developed countries. This is so despite the fact that in developed countries death rates are lower age-for-age than in the developing countries. This apparent anomaly results from the combination of the large proportions of persons in the young age groups and low proportions of older persons in the developing countries. The reverse is true in developed countries; mortality rates are quite low in the young ages such as 5 to 20, and of course are high in the older ages. The result is that in developed countries crude death rates are almost double, or about 10 per 1,000 per year.

Although the largest improvements in mortality rates during the past three decades have been made in developing countries, the improvements in developed countries are also significant. Declines in infant mortality in developed countries have been remarkable. In 1950, very few countries had infant mortality rates under 25 per 1,000 per year, and many had rates ranging up to 50, and more. Today, six countries have rates below 10, and 25 countries have rates below 20. (The United States has a rate of 13-14).

Curiously, the causes of these very large changes in mortality are not well known. The increases in the number of physicians and other medical personnel, and of medical facilities, have not been sufficiently large or rapid to account for much of the change. Preston's analysis concludes that only 16 percent of the change from the 1930s to the 1960s was attributable to improvements in economic conditions. He also concludes that improved nutrition was not a major cause of the decline. Lacking even reasonably hard evidence, students of these changes have come to say that the reduction in mortality rates is due to a combination of causes such as improved communication and transportation, more responsive governments, improved sanitation, the widespread use of the insecticide DDT, and the availability of antibiotics. Currently, there is controversy as to whether mortality declines have slowed appreciably [discussed in another article below].

Mortality differentials are at least as great within countries as among different countries. Studies in Asia, Africa, Latin America, and the United States show that child mortality is two to five times as high among mothers with no education as among mothers with high school education. Differentials increase as education of the mother increases. Mortality differentials are also associated with other socioeconomic indices such as income, but the differentials are particularly strong with education of the mother.

Fertility Trends

Overview. The crude birth rate of the world was about 36 births per 1,000 population per year in 1950; it has been reduced by about 20 percent and is below 30 today. But the world is divided into high and low fertility countries, with the developing countries having both high fertility and the bulk of the population (74 percent, or 3.3 billion persons).

The more developed countries had low fertility in 1950, an average crude birth rate of about 23, but there has been a remarkable decline in fertility in almost all developed countries since then. The average decline has been almost one-third, and the level of crude birth rates today is about 16 (Fig. 1). A few of the developed countries have

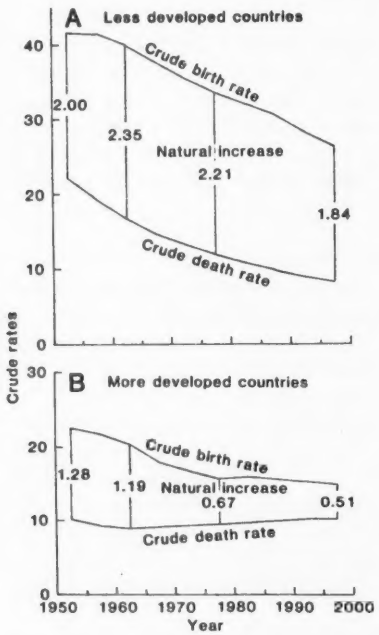
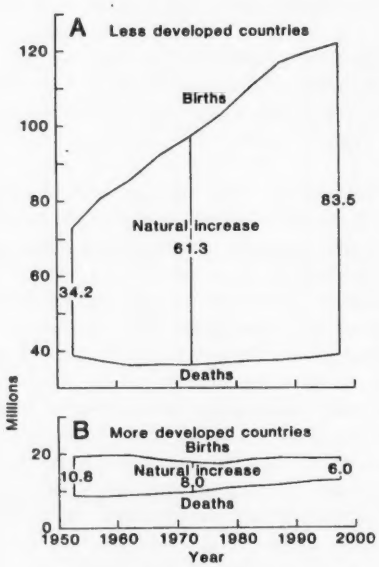


Fig. 1. Crude birth and death rates and percentage natural increase, 1950 to 2000 (United Nations medium assumptions).



Average annual number of births, deaths, and population increase, 1950 to 2000 (United Nations medium assumptions).

more deaths than births (both of the German states), and many have rates of reproduction that if continued would result in no or negative growth. The average rate of growth of population among these countries is well under 1 percent, and is likely to decrease further during the next few decades. Thus, population growth among the more developed countries poses few problems in terms of maintenance of current levels of living.

The developing countries present a different picture. In 1950 their populations numbered 1.7 billion, and death rates were high, more than 23 per 1,000 population per year. The revolution in mortality has almost halved the crude death rate to 11 or 12 today. Fertility was high in 1950, about 42 per 1,000. Thus, the rate of growth was slightly less than 2 percent per year in 1950. Major changes in fertility have also occurred in many developing countries, though overall fertility changes have been less marked than the decline in mortality. The figures show a decline in the crude birth rate from 42 to 33--a decrease of 9 points, or about 20 percent. Changes in fertility have been dramatic in Asia and the Pacific, substantial in Central and South America, and hardly noticeable in Africa. In Asia, where the bulk of the population lives, the crude birth rate declined by 25 percent from more than 41 to 31 per 1,000 population per year. In the Americas the decline was 16 percent--from more than 41 to less than 35 per 1,000 per year. The data for many African countries are woefully inadequate, and birth rates and trends may not be accurately reflected in the figures available, which suggest a crude birth rate of about 48 in 1950, and perhaps dropping a couple of points to 46 in 1978. Only two countries in Africa-Tunisia and Mauritius--have had appreciable changes in fertility over the 30-year period. Egypt had a decline in its crude birth rate in the late 1960s and very early 1970s, but since that time the crude birth rate has increased. Most of the changes in its crude birth rates are attributable to changes in the number of persons marrying; a small part of the change is due to a modest decline of 7 to 8 percent in marital fertility from the mid-1960s to the mid-1970s.

Developed countries. All developed countries experienced fertility declines from 1950 to 1978 except Ireland and Argentina. Declines ranged from about 10 percent in Spain to more than 40 percent for five countries. Overall, fertility declined by 32.3 percent in developed countries. The two largest developed countries, the Soviet Union and the United States, had similar rates at both periods, with the United States having slightly lower rates in both years. Decreases in fertility rates were common to large and small countries, to capitalist and socialist, to European and non-European populations, to Catholics and Protestants.

The current levels of fertility are remarkably low for almost all of the developed countries. The Federal Republic of Germany has a birth rate of less than 10, well below the replacement level, and 13 additional

countries in northern and western Europe have rates of less than 15. All of these countries plus Canada, the United States, and Japan have below-replacement levels of fertility. A few of the 35 developed countries do not have low fertility: Albania, with a crude birth rate of 33 per 1,000 population per year when last reported, and Israel and Argentina, with rates of 25, are the major exceptions. Ireland and Uruguay also have crude birth rates around 21. All other developed countries have crude birth rates of less than 20 per 1,000 population per year.

While most developing countries are seeking to reduce their birth rates, Eastern European countries, where legalized abortion came to be associated with, or indeed produced, a quite low birth rate, are now making determined efforts to increase theirs, with occasional signs of success. Negative measures include tightening of restrictions relating to induced abortions and reduction in the availability of contraceptives. Positive measures are a liberal increase in monthly wages for couples having three or more children, interest-free loans for purchase of an apartment or house and of household furnishings with, for example, 20 percent of the loan being cancelled at the birth of the first child, 30 percent for the second, etc. In addition, some other developed countries have pronatalist ambitions or milder policies: Israel, France, Finland, Greece and Argentina. The Netherlands reports the goal of achieving a stationary population, and Japan, that a stationary population is "estimated and expected."

Developing countries. There are 92 developing countries with a population of 1 million or more, but 2.6 billion, or 80 percent of the population of all developing countries live in 16 countries. Population data, crude births rates, and percentage changes for 1965 and 1975 are given for those countries in Table 1 (excluding Vietnam for lack of data). These countries vary enormously in ethnic origin, culture, level of development, population policy, and changes in fertility. Brazil and Nigeria do not seek to reduce the rate of population growth, but in recent years have adopted a policy of supporting family planning for reasons of health and as a human right. Iran had a policy to reduce its rate of population growth, but it is unlikely that the present government will continue that policy. Burma has a pronatalist attitude. It recognizes family planning as valid on maternal and child health grounds, but contraceptives are not easily available; the importation of contraceptives is illegal and family planning clinics are not allowed. All the other countries have adopted policies to reduce the population growth rate.

There has been no significant reduction in fertility in Bangladesh, Burma, Iran, Pakistan, or Nigeria, but there is evidence of change in each of the other ten countries. The decline has been particularly strong (more than 25 percent) in China, South Korea, and Thailand,

Table 1 Crude birth rates and crude birth rate decline for 1965 (or later) in less developed countries with populations of 35 million or more.

Country*	1980 population (millions)	Crude birth rate		Percentage change in crude birth rate 1965 to 1975 (or later)
		1965	1975 (or later)†	
China	975	34	22[8]	−35
India	694	43	36	−16
Indonesia	152	46	36	−22
Brazil	122	42	33[7]	−21
Bangladesh	89	48	48	‡
Pakistan	82	47	47	‡
Nigeria	77	49	49	‡
Mexico	70	44	37[8]	−16
Philippines	51	44	34[7]	−23
Thailand	48	44	33	−26
Turkey	45	40	34	−16
Egypt	42	41	37	−10
Iran	38	45	45	‡
South Korea	38	32	22	−29
Burma	35	40	40	‡
Total	2523	40	33	−20

*Excludes Vietnam with an estimated population of 52 million; information on vital rates over time is not thought to be reliable. †The crude birth rates are for 1975 unless a later year is specified with a superscript 7 or 8 for 1977 and 1978, respectively. ‡No significant change.

and has also been quite impressive (more than 20 percent) in Brazil, Indonesia, and the Philippines. The data on which these estimates are based are quite recent for several countries including Brazil, Mexico, and the Philippines.

The rate of population growth in developing countries is down from its recent peak, but not by much (Table 2). It is now about 2.2 percent per year with a country range from about 1 percent to well over 3 percent. Fertility declined more rapidly than mortality after 1965 in Asia and Latin America, and the rate of natural increase was smaller in Latin America and much smaller in Asia during the last 5 years than during 1960 to 1965. Fertility and mortality declines were about equal in North Africa and the Middle East, but in sub-Saharan Africa fertility did not decline whereas mortality probably did, and thus the rate of natural increase there continued to climb to an estimated 2.9 percent per year.

Table 2 Rates of population growth.

Area	Percentage of natural increase			Percentage change 1960 to 1965/ 1975 to 1980
	1950 to 1955	1960 to 1965	1975 to 1980	
World	1.77	1.99	1.81	− 9.0
More developed	1.28	1.19	0.67	−43.7
Less developed	2.00	2.35	2.21	− 6.0
Africa	2.16	2.49	2.91	+16.9
Latin America	2.72	2.77	2.66	− 4.0
Asia	1.88	2.06	1.37	−33.5

The net effect of these differing trends in the developing countries was a modest decrease of about 6 percent in the rate of natural increase, from 2.35 percent in 1960-65 to 2.21 percent in 1975-80, according to the United Nations. Fertility decreases were significantly larger, a decrease from 40.0 to 33.6, or -16 percent. Mortality rates also declined from a crude death rate of 16.8 in 1960-65 to about 12 during the past 5 years. In developed countries there has been a continuing decrease in fertility, but mortality rates have more or less stabilized for the present--the countervailing product of continuing improvement in mortality offset by population aging. Rates of natural increase have thus fallen with fertility decline and are now only about two-thirds of 1 percent per year. But the demographic momentum in the developing sector remains particularly strong, regardless of any realistically favorable developments of the next years.

China's reconciliation of a Marxist "theory" of population with "planned" population growth has attracted attention due to the sheer magnitude of its population. Recognition that rapid population growth is detrimental to the economy of China did not come easily or quickly. In June 1957, Professor Ma Yinzhu, an economist, then president of Beijing University, published a "New Population Theory," arguing that population growth in China should be controlled. He was denounced in the press, and in 1960 was removed from his university position. By 1974, however, Chinese officials had begun talking about the need for planned births as well as planned production. In March 1978 the Chinese announced that their goal was to reduce the annual rate of population growth to less than 1 percent within 3 years. In July 1979, a public apology was made to Professor Ma, and he was officially told that "the two criticisms of your new population theory before 1958 and after 1959 had both been erroneous."

The official view in China today is that population growth has been, and is, too rapid, and must be reduced. The stated goal is to reduce the rate of growth from 1.2 percent in 1978 to 0.5 percent in 1985 and to zero by the year 2000. Population growth is viewed as being detrimental to the development of the economy because it decreases the speed of capital accumulation; it hinders the rapid elevation of the scientific and cultural level of the entire population, and it is detrimental to the improvement of the people's livelihood. China seeks to lessen rates of population growth through late marriage, the availability of abortion and contraceptive services, emphasis on planning the number of children born each year, and recently, a campaign strongly advocating a one-child family. Decreases in rates of population growth are to be achieved by mobilization of party committees on all levels; strengthened propaganda and education; by a system of awards and penalties inducing conformity to the stipulated fertility norms; and by improving family planning services and programs.

Most estimates of the population of China fall within the range of 950 million to 1,000 million, but a reasonably firm figure must await the 1981 census. The Chinese announced a crude birth rate of 18.34 and a death rate of 6.29, and thus a growth rate of 1.2 percent, in 1978. These figures are said to be estimates derived from incomplete data. Whatever the precise figures, it is evident that China has achieved a remarkable improvement in health conditions and in the reduction of fertility.

South Korea and Thailand have had crude birth rate decreases of more than 25 percent since 1965, although Thailand's current rate is still moderately high, in the low 30s. South Korea has had a rapidly growing economy and also a vigorous family planning program since the early 1960s. Thailand has had less rapid economic development but has had a sustained, moderately strong family planning program.

Indonesia has a very low per capita income, a low rate of economic growth, and high fertility. It is thought that fertility changed but little from 1950 until the late 1960s; but there are changes since that date. In 1968 Indonesia embarked on a large-scale family planning program which has been well organized since 1970; indeed, it is commonly thought to be one of the most vigorous family planning programs in the world. The number of family planning acceptors has been very high, particularly in Java and Bali. With the large number of family planning acceptors, one would expect some decrease in fertility. There is considerable lag between collection of data from sample surveys and detailed analysis of the results; and there is controversy as to how much Indonesia's fertility has fallen, but certainly it has fallen during the 1970s.

India is among the poorest countries in the world and, despite ambitious development plans starting in the early 1950s, per capita income and many other indices of development remain low. India was the first country in the world to adopt a population policy designed to reduce rates of population growth in 1952. A relatively small family planning program in the 1950s was expanded to a large-scale program in the mid-1960s. The family planning efforts have been heavily dependent on male sterilization in some states. Strong pressure, and apparent coercion, led to a tremendous increase in the number of sterilizations in 1976, and these strong measures were a principal factor in the subsequent overthrow of the government.

The evidence is unmistakable that fertility has fallen significantly in India during the past 15 years even though the level of fertility is not known with precision. The current level of the crude birth rate, estimated at 36 per 1,000 population per year, is known with more accuracy than the rate during the early and mid-1960s. The level at the earlier dates may have been closer to 45 or 46 than to the 43 shown in Table 1.

This account is concentrated on large countries because that is where most of the people of the world live. Fertility declines in smaller countries have often been near spectacular, and some of these have been highly publicized. Fertility declines in Hong Kong (36%), Singapore (40%), and Taiwan (30%), are frequently mentioned, but equally impressive declines have occurred in Cuba (40$), Mauritius (29%), Chile (29%), Colombia (25%), Panama (22%), and Costa Rica (29%).

The causes of recent fertility declines, in both developing and developed countries, will probably remain in some dispute for at least several years; such is the nature of causal analyses of highly complex circumstances. But some degree of consensus seems to be emerging to the effect that:

1) Marital patterns (age at marriage, proportion of reproductive age spent within marriage) account for a substantial part of the recent decline, perhaps 35 to 45 percent in developing countries; but marital fertility itself is the major component.

2) Social setting or development level has a substantial relationship to fertility decline, certainly on a holistic basis and probably selectively with regard to health and educational status.

3) Family planning programs have a significant independent effect, certainly in developing countries with favorable social settings, and also under certain conditions in countries with less favorable settings (including the three largest: China, India, and Indonesia). Moreover, the longer the program and the clearer its demographic intent, the greater its effect.

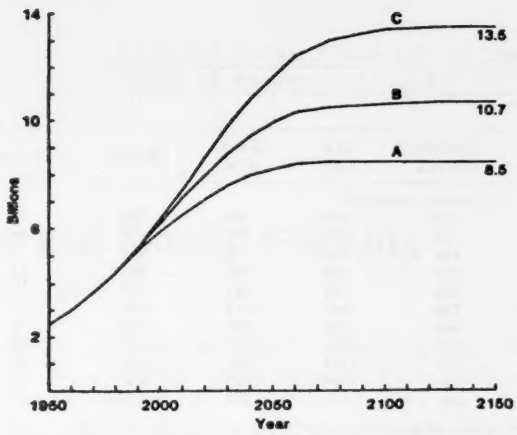
4) Social setting and family planning programs together predict or "explain" (statistically) a large part of fertility decline.

Prospects

Despite the uncertainty about predicting the future, there is consensus on several major points:

1) Growth rates in developed countries are low, and it is likely that they will remain so. Fertility could increase, but the two-child family seems to be more nearly the norm than a three-child family. The present population of developed countries is just over 1.1 billion; 20 years from now it is likely to be less than 1.3 billion. Few serious analysts disagree with this generalization.

2) Growth rates in developing countries are high. These will be moderated somewhat during the next two decades, but the momentum of population growth is high, and this momentum will lead to larger and larger absolute increases in the population of the developing countries during the remainder of this century even though fertility rates continue to decline (see Figs. 1 and 2). This momentum of population growth is



If the world attained replacement fertility in	World population would then stand at	And world population could be expected eventually to stabilize at
(A) 2000–2005	5.9 billion (2000)	8.5 billion
(B) 2020–2025	8.0 billion (2020)	10.7 billion
(C) 2040–2045	10.8 billion (2040)	13.5 billion

Fig. 2 Momentum of world population growth. The fertility decline is assumed to begin in all cases with the 1975 to 1980 level of population growth. Thus, replacement-level fertility (2.1 to 2.5 births per woman) by 2000 to 2005, for example, implies a gradual reduction of fertility over a 20-year period. [From (*23*)]

caused by an age structure with a relatively large proportion of young persons who will move into and increase the number in the reproductive ages for at least 15, and more likely more than 20, years.

3) Most population projections for the year 2000 cluster around 6 billion. The United Nations produces three projections; just under 5.9 billion, 6.2 billion, and 6.5 billion. Thus, it is projected that the population of the world will increase by about 1.4 billion to 2.0 billion during the next 20 years. Most analysts favor figures that imply a growth of 1.5 billion $\pm$ 200 million.

4) The medium assumption of the United Nations projects a population increase of 40 percent by the year 2000. Africa is expected to have the most rapid growth, more than 75 percent, and Latin America the next most rapid with about 65 percent growth. South Asia would grow by 55 percent and East Asia by 24 percent according to these projections. Northern America and the Soviet Union would grow by 17 to 18 percent. Europe would grow very slowly, by only 7 percent. The record of population growth since 1950 by major areas, and projected growth until the year 2000 are shown in Table 3.

5) There is lack of agreement as to when fertility will begin to decline, and at what rate, in Black Africa, Bangladesh, and Pakistan.

6) Nor is there agreement as to what the size of the world's population will be when it ceases to grow. A few optimistic analysts set

Table 3. Population trends in the eight major areas of the world, 1950 to 2000, as assessed in 1978

Year	World	Africa	Latin America	Northern America	East Asia	South Asia	Europe	Oceania	Soviet Union
				Population (millions)					
1950	2513	219	164	166	673	706	392	13	180
1955	2745	244	187	182	738	775	408	14	196
1960	3027	275	215	199	816	867	425	16	214
1965	3344	311	247	214	899	979	445	18	231
1970	3678	354	283	226	981	1111	460	19	244
1975	4033	406	323	236	1063	1255	474	21	254
1980	4415	469	368	246	1136	1422	484	23	267
1985	4830	545	421	258	1204	1606	492	24	280
1990	5275	630	478	270	1274	1803	501	26	292
1995	5733	726	541	281	1340	2005	510	28	302
2000	6199	828	608	290	1406	2205	520	30	312
				Average annual rate of increase (percentage)					
1950 to 1955	1.77	2.16	2.72	1.80	1.85	1.86	0.79	2.25	1.71
1955 to 1960	1.95	2.36	2.78	1.78	1.99	2.24	0.84	2.18	1.77
1960 to 1965	1.99	2.49	2.77	1.50	1.94	2.44	0.90	2.09	1.49
1965 to 1970	1.90	2.61	2.67	1.11	1.75	2.52	0.66	1.96	1.09
1970 to 1975	1.84	2.71	2.64	0.87	1.62	2.45	0.61	1.82	0.84
1975 to 1980	1.81	2.91	2.66	0.83	1.32	2.49	0.39	1.47	0.94
1980 to 1985	1.80	2.97	2.65	0.96	1.16	2.44	0.36	1.41	0.94
1985 to 1990	1.76	2.93	2.58	0.91	1.14	2.31	0.35	1.37	0.85
1990 to 1995	1.66	2.81	2.46	0.76	1.01	2.13	0.37	1.30	0.70
1995 to 2000	1.56	2.64	2.34	0.61	0.95	1.91	0.38	1.19	0.64

Source: United Nations, World Population Trends and Prospects by Country, 1950-2000, Summary of 1978 Assessment (New York, 1979).

the figure around 8 billion, but a population of 10 billion to 12 billion seems more realistic. For example, if replacement fertility were reached in every country of the world by the year 2000 the population would grow to 8.5 billion (see Fig. 2). But such a rapid decline in fertility seems very unlikely. If replacement fertility were achieved by the period 2020 to 2025, the population of the world would grow to 10.7 billion. If the achievement of replacement fertility were further delayed, say to the period 2040 to 2045, the population of the world would grow to 13.5 billion. There seems to be an emerging consensus that if the leaders of the major developing countries view rapid population growth as an impediment to economic development and act accordingly, and if the donor community also continues and perhaps increases assistance to such countries, the population of the world might plateau around 10 billion. But larger numbers are all too possible.

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Men and Family Planning

Bruce Stokes

[The major targets of family planning programs over recent years have been women. Partly this results from some prevailing attitudes of men, partly from males having less attractive contraceptives than those for females. Men and women ought to share their family responsibilities. The following article discusses the role men can take in family planning.]

Men are the forgotten sexual partner in family planning programs. Despite the fact that conceiving a child always involves two people, society often ignores the interest men have in planning their families. Male contraceptives are treated as second-class birth control methods, and in many countries their advertisement is banned. Until recently, there has been little research into new male methods of birth control. And few organized family planning programs have targeted men as clients.

Men's potentially positive role in family planning has so often been neglected because of the negative attitudes many men hold toward birth control. In the industrial world, men frequently use the availability of effective female contraceptives as an excuse for not using any birth control themselves. In the Third World, some men still insist on having the sole right to decide whether and when to have a child; many deny their wives access to contraception because they fear it will encourage promiscuity. And everywhere there are men who oppose birth control and women's changing roles in society, possibly because it takes from them their power to father an unlimited number of children and seems to leave them with a diminished position in the family.

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Society can ill afford to have men play this peripheral or negative role in family planning. The world faces the daunting prospect of supporting 10 to 12 billion people by the middle of the next century unless birth rates fall rapidly. More than half the world's couples do not use contraception, and they are concentrated in the poorest parts of the Third World. Many of these societies are patriarchal, and men still dominate family decisions. The ultimate success of birth control programs in these countries may rest on the availability and use of effective male contraceptives and the involvement of men in family planning programs.

The health of both men and women could improve if men play a greater role in birth control. There is clear evidence now of various health risks posed by women's prolonged use of oral contraceptives or an intrauterine device (IUD). Condoms, however, relieve women of these problems without creating a health problem for men. Increased reliance on condoms could also help curb the spread of sexually transmitted diseases, as compared to reliance on the major female contraceptive methods.

Until two decades ago, most couples used male contraceptive methods, if they used any at all. With the introduction of the pill and the IUD, female birth control methods soon became dominant. Now the pendulum seems poised to swing back, and men and women may soon share more of the responsibility for contraceptive use. In the United States, condom sales are already on the increase. Several Asian countries have expanded their vasectomy programs, and recent progress in making the operation reversible bodes well for vasectomy's future acceptability. A male contraceptive pill might be on the market by the end of the century. And male family planning programs have struck a responsive chord in the United States as well as in parts of the Third World. These changes hold the promise of men participating more actively in family planning: by using effective male contraceptives, by supporting women in their choice of birth control, men can assume a larger share of the burdens of contraception and the joys of having children.

Male Contraception: Traditional Methods

Of the more than 250 million people in the world currently using some method of birth control, about one out of three rely on male contraception. This portion has steadily decreased in recent years as the pill, the IUD, and female sterilization have become widely available. Yet male birth control is anything but obsolete. Some 37 million men use condoms, about 35 million have had vasectomies, and millions more rely on withdrawal. By comparison, each of the major female methods has 50 to 65 million users worldwide (see Table 1).

Figures such as these mask a curious geographic split in male and female contraceptive use around the world. The small number of couples in the Third World who use birth control overwhelmingly prefer female methods, despite the fact that male methods have been in use longer and

often are simpler and cheaper. Most of the people who rely on male contraception live in industrial countries. One out of five Americans, one out of two Italians, and four out of five Japanese use a male method of birth control regularly.

Table 1: ESTIMATED NUMBER OF PEOPLE USING MAJOR BIRTH CONTROL METHODS, 1980

Method	Number (Millions)
Female Methods	
Sterilization	65
Oral Contraceptives	58
Intrauterine Device	52
	175
Male Methods	
Condom	37
Vasectomy	35
	72

Source: Agency for International Development.

Condoms enjoy their greatest popularity in Japan, where 79 percent of married couples rely on them or have done so in the past, often in conjunction with the rhythm method. Condoms are also quite popular in the United Kingdom and Sweden, but are little used in most developing countries. Vasectomies, on the other hand, are widespread in both the United States and India. More than 10 percent of all married American men of reproductive age have been sterilized. And since 1966 more than 20 million Indian men have had vasectomies. Elsewhere, the operation is relatively rare.

A closer look at each of the major male methods sheds some light on cultural and geographic differences in birth control use. Withdrawal, technically known as coitus interruptus, is one of the oldest means of family planning, male or female. The Book of Genesis in the Christian Bible refers to Onan, who spilled his semen on the ground. More specifically, Islam permits withdrawal provided that the woman gives her consent. Throughout its long history, coitus interruptus has been a much maligned means of preventing births. It has the highest failure rate of any major method of contraception. In addition, the interruption of sexual activity necessitated by withdrawal can markedly diminish the physical pleasure of both partners. It also requires the man to be responsible at the moment his resolve may be the weakest, and asks the woman to place her full trust in that resolve.

Yet withdrawal costs nothing, it involves no creams, pills, or devices that can be inadvertently forgotten, and it does not require a

medical prescription. Moreover, withdrawal's demographic record as a family planning method is noteworthy. The falling birth rates in nineteenth century Europe, and more recently in Eastern Europe, were in large part the result of coitus interruptus backed up by abortion. When practiced in conjunction with other more effective methods or when combined with periodic abstinence during a woman's most fertile periods, withdrawal can indeed be a successful means of birth control.

Like withdrawal, the condom has seldom been treated seriously as a contraceptive. The historical association with venereal disease has long linked the condom with "illicit sex." A gentleman, it was thought, would use one with a prostitute but certainly not with his wife. Yet the data on condom usage belie this image. Until the mid-sixties the condom was the principal method of birth control in the United States. With the advent of the pill and the IUD, condom sales fell and by the mid-seventies, only 7 percent of all married couples were using condoms. Since then, however, the condom has experienced something of a revival and Americans bought about a half billion of them in 1980.

The nature of the condom may in the long run be its biggest drawback. At least since Casanova's day, men have complained that condoms reduce sexual sensation. Thinner condoms and ones made of different materials could remedy some of these problems; a tough elastic membrane that could transmit heat and tactile stimulation is needed. It is also possible that by the end of the century a more effective spermicide-coated condom or a contraceptive film that would cover the tip of the penis could be available. These innovations could undoubtedly make the condom a more attractive contraceptive option. In any case, as researchers who have studied human sexuality often point out, the pleasure connected with sexual activity stems more from the attitude of the two people involved than it does from penile sensation, so condom use does not have to limit sexual fulfillment.

The number of condom users is certain to increase in the years ahead. Commercial condom distribution is expanding, especially in the Third World. Concern about the health effects of women's use of the pill or the IUD will lead many couples to rely on the condom, often in conjunction with other female methods. The rising incidence of venereal disease is already encouraging many individuals who have several sexual partners to protect themselves by using condoms.

Vasectomies. In the last decade, the most dramatic change in male contraceptive use has been the threefold increase in the number of vasectomies. This simple operation involves an incision in the scrotum to cut or block the vas deferens, the two tubes that carry semen from the testes to the penis. In the United States, over 700,000 American men had had vasectomies in 1971. By the end of the decade, however, nearly six million men had been sterilized, and more couples relied on male than on female sterilization as their method of birth control.

Outside the United States, India was one of the first countries to use vasectomies in its national family planning program, and with dramatic success. Some observers ascribe the popularity of vasectomy to Hindu culture: for many Indians, there is great virtue in celibacy, in part because it is believed that men enhance their strength and power by withholding their sperm. Sterilization, many men may think, confers the same benefits without having to forgo sexual relations. The vast majority of Indian sterilizations have been voluntary. But in 1976 the government made sterilization the cornerstone of a crash campaign to slow the Indian birth rate. Within 12 months, six million vasectomies were performed along with about two million female sterilizations. Police and administrators at times coerced people into having a sterilization merely to meet local quotas. Opposition to these practices rose sharply and helped overturn the government. Nevertheless, by 1979-80 interest in this male birth control method had revived and about 460,000 Indian men voluntarily had vasectomies.

Many men have sincere personal anxieties about sterilization. They mistakenly worry that after the operation they will lose interest in sex and become impotent. A more difficult problem may be the growing uncertainty about the operation's long-term physical side effects. When sperm can no longer move through the vas deferens, they often pass into the blood stream and stimulate an immune reaction. The health consequences of the presence of sperm antibodies in the blood over a long period of time are unknown; only further research will determine whether they will lead to any higher incidence of health problems in old age.

Probably the main objection most people have to vasectomy is that the operation is permanent. Although some studies suggest that most vasectomies can be reversed through microsurgery, the technique has been tried on a relatively small number of men. Moreover, the procedure is complicated and expensive, so it is unlikely that adequate reversal facilities will soon be widely available, especially in the Third World. Researchers are now trying to design a plug or a valve to implant in the vas deferens that would make reversal easier. Studies are also under way with a chemical sterilization by injection. But it will be years before any of these methods are available, if ever. For the time being, men contemplating sterilization must consider the decision a permanent one.

The number of men who have had vasectomies is likely to increase substantially by the end of the eighties. China and several other countries in Asia and Latin America are expanding their male sterilization programs. Studies by Charles Westoff and James McCarthy of Princeton University suggest that as members of the American postwar baby boom generation complete their families, as many as 30 percent of the men will choose to be sterilized.

Family Planning Programs for Men

Despite the fact that men have practiced birth control for years, they have generally been excluded from organized family planning programs. However, the assumptions that shaped exclusively female family planning services have begun to change. Today, women argue that men should share the nuisance as well as the health risks of contraception. And some men have suggested a holistic approach to family planning, one that would include a range of male reproductive health services. Family planning officials and governments now have little excuse for writing off half the world's contraceptive audience.

To date, however, only a small number of male family planning programs have emerged, the great majority of them in the developed countries. Some provide traditional clinical reproductive health services. Others concentrate on increasing the availability of condoms. The most innovative programs attempt to reshape men's attitudes toward family planning and a range of related issues. There are not yet enough projects to draw definite conclusions, but existing efforts offer insights into some of the difficulties and the advantages of involving men in planning the number and spacing of their children.

In the early seventies, an attempt was made in Ghana to improve methods of providing rural primary health care, which included family planning. Mobile family planning teams traveled from village to village providing family planning services in the Danfa region north of the capital city of Accra. Their work was supplemented by the staffs of maternal-child-health centers and by village-based primary health care workers. Although the project started out as a traditional, female-oriented program, it soon became more of a male effort when nearly half the clients were men. Over half of these even requested foam, indicating that many preferred to have their partners use birth control rather than use male methods themselves. In the male-dominated society of Danfa, men often turned out to be more conscientious about the use of birth control than women. They also proved to be better family planning advocates; more men than women tried to persuade their friends to use contraception. And men who chose a birth control method either for themselves or for their partners reported that their partners had fewer pregnancies than the women who participated directly in the program.

By the time the project concluded, contraceptive use in the Danfa region had increased somewhat and fertility had fallen in some areas. While there is some controversy over interpretation of the data, an evaluation of the program by the School of Public Health at the University of California at Los Angeles suggests that at least one-half the fertility reduction in Danfa is related to male acceptance of birth control for themselves or for their partners.

The results of the Danfa program have several explanations. According to the mores of the area, men have some financial and social responsibility for children born out of wedlock. Thus the use of condoms permits some premarital or extramarital sexual activity without subsequent obligations. Moreover, educational and work opportunities for men are increasing in the area. Men, like women, seem to want smaller families when it is clear this will improve their opportunities for a better life for themselves and their families. When the men of Danfa were asked to explain for themselves why they chose to practice contraception, their responses expressed a remarkably unselfish concern. The most common reason given was the improvement and preservation of the health of their children. Men were also concerned with protecting their wives' health and with making it easier to educate their existing children.

The Danfa program demonstrates that medically oriented male family planning programs can increase men's use of contraception. In fact, the men in Danfa preferred visiting the mobile clinics to buying their condoms in a store. Nevertheless, as long as male family planning programs are tied to formal health services they will be limited by the clinics' mobility, by the cost of providing services through highly trained personnel, and by the stigma often attached with visiting a doctor. The greatest opportunity for increasing male use of birth control lies outside the clinic, in the community.

The distribution of free condoms by trained counselors is an effective way to involve men initially in family planning. But it is an expensive and time-consuming process. Most nations have scant resources for such efforts. Reaching a broad segment of the male population on a sustained basis requires the integration of condom distribution into commercial marketing networks. Even in the poorest parts of the world, most people shop at neighborhood stores or are visited daily by itinerant vendors. By using these commercial outlets to sell condoms at low subsidized prices--an approach known as social marketing--family planning programs have been able to increase contraceptive use and broaden male involvement in family planning. [See Development Digest, January 1979, pp. 29-57.]

In India and Sri Lanka, sites of the oldest social marketing programs, a visitor to even the smallest village is likely to see striking but tasteful advertisements for condoms on the doors of greengrocers and tea shops. Condoms are marketed with a flair previously reserved for selling soap or candy. Brightly colored packaging and catchy brand names seem to have spurred condom purchases. In India, sales grew from less than 25 million in the late sixties to 160 million in 1978/79. In Sri Lanka, condom sales leapt from about a half million in 1972 to nearly six million in 1978.

It is sobering to realize, however, that even these strikingly successful condom promotion programs have so far reached only a small portion

of the men of reproductive age. Getting men to think positively about birth control and to put those attitudes into practice takes more than condom availability; it will ultimately rest on a more comprehensive change in male consciousness. Whether in Nigeria, China, or the United States, it is important to shape men's attitudes toward family planning when they are young.

Much of what men learn about their bodies, about sex and reproduction, about contraception, and about how to relate to women comes from discussions and interactions with friends, particularly as they are growing up. For generations, this learning process has perpetuated male stereotypes. Today, some family planning programs are attempting to use this powerful educational force to help men break out of old molds. In southern Nigeria, for example, the Lagos Family Health Clinic formed a Fathers' Club in 1974. The group meets one evening a month and is run by elected representatives of the members. It provides a forum for health education, helping men understand the link between family planning and the well-being of their wives and children. In any one year, about 20 percent of the fathers in the area attend a club meeting, enough to create a small group in the community that influences other men to be favorably disposed toward family planning.

In China, birth control has become the responsibility of small groups of men and women in factories, neighborhoods, and villages throughout the country. Following government guidelines, the groups decide on the number of children that should be born each year and then allocate the births to eligible couples. No longer can men force their wives into one pregnancy after another, to the detriment of the women's health. Self-criticism and peer pressure encourage men to consider the interests of their wives, their children, and their community when making family planning decisions. Although male birth control methods are so far not actively encouraged in most areas, this may begin to change when and if new and more attractive male contraceptive methods become more widely available and as taboos about vasectomy break down.

The involvement of men in family planning is certainly not new. India has had an official vasectomy program for two decades. What is new today is the realization on the part of some governments that a range of birth control services for men should be available. While particular experimental male projects may have varying degrees of success, this underlying commitment to greater male involvement in family planning suggests that one day men will have contraceptive and reproductive health programs comparable to those now provided for women.

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Prospects for Improved Contraception

Linda Atkinson, S. Bruce Schearer, Oscar Harkavy
and Richard Lincoln

[After a general review of the trends in global research on methods of contraception, this article describes four potential new methods which the authors consider significant, noting their advantages and drawbacks and the status of the research on them.]

Like most revolutions, the contraceptive revolution disappointed some whose expectations of it were unrealistically high. Two decades ago, when the oral contraceptive was brought to market and the IUD was reborn in antiseptic plastic and stainless steel, many scientists voiced optimism that that was only the beginning. It would not be long, we were told, before the perfect contraceptive would become available--highly effective, safe, acceptable, inexpensive and simple to administer and distribute. By now, it is generally recognized that there can never be such an ideal contraceptive, and that an array of methods is needed for people who live under different circumstances and have differing preferences and requirements. Each method has its advantages and drawbacks, and it is likely that there will always be some tradeoff between effectiveness and risk.

Granted all these qualifications, the distance from the scientist's imagination to the couple's bedroom has proved to be greater than some had believed. The array of vaccines, menses inducers, male pills and chemical sterilants first heralded a dozen or more years ago

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are for the most part still in early stages of development--for want of money, knowledge, manpower or all three. Not a single new contraceptive chemical entity has reached the marketplace since the introduction of the synthetic steroid norgestrel in 1968. The need for improved contraceptives has become more acute as the reputations of the pill and the IUD have been tarnished by an accumulation of medical reports indicating that they are not as safe as some had hoped, although not nearly as dangerous as some had feared. There have been a number of improvements in the safety or effectiveness of existing methods, but more basic innovations are needed.

Increasingly widespread utilization of the most effective modern methods of birth control associated with vigorous national family planning programs in a number of developing nations--including some very populous ones such as China, Indonesia, Mexico and Thailand--have helped bring down birthrates and explosive population growth rates dramatically. Although specific estimates differ, there is now general agreement that the rate of population growth in the developing world has been slowed, and that the trend toward further decline in growth rates is likely to continue. However, the very large number of unintended pregnancies and births that continue to occur in countries where all current methods, including abortion and sterilization, are widely available is evidence that today's methods are not sufficient to enable couples to realize their reproductive intentions even under very favorable circumstances, much less under conditions where storage, distribution and administration of contraceptives are problems.

Oral contraception, the IUD and sterilization are the cornerstones of current service delivery programs. The pill, although highly effective, is considered unsafe for older women who smoke or have other conditions (such as obesity or high blood pressure) that place them at high risk of cardiovascular disease. The advisability of the IUD, on the other hand, is questionable for young women who have not yet begun childbearing, because of the danger, however small, of infection that might compromise future fertility. Widely publicized information about health risks--sometimes sensationalized--has led a number of young women in developed countries to abandon the pill and the IUD. As family planning programs expand, pill and IUD use in developing countries continues to increase, but discontinuation of both methods is often relatively high; the first-year discontinuation rates in developing countries run as high as 20-40 percent of new pill and IUD users. And it is unlikely that the political and religious controversies over abortion will be settled in the foreseeable future. In a number of countries, especially in the Muslim world, it is probable that abortion will remain illegal for some time to come.

Under these circumstances, it seems unlikely that the present technological base for birth planning will be adequate to support the addition of 500-600 million more users over the next few decades. New re-

versible methods for men and women, as well as less intrusive and simpler means of sterilization, continue to be desperately needed in industrialized and in developing countries. What is the current state of contraceptive development, and what are the prospects for the future?

The Contraceptive R&D Process

Producing and marketing a new contraceptive involve investment in six major types of activity: 1) the training of scientists to conduct research, and the support of those institutions that educate them; 2) basic scientific research in reproduction; 3) mission-oriented research; 4) applied research and development (R&D); 5) product introduction; and 6) evaluation of the effectiveness and safety of methods in use.

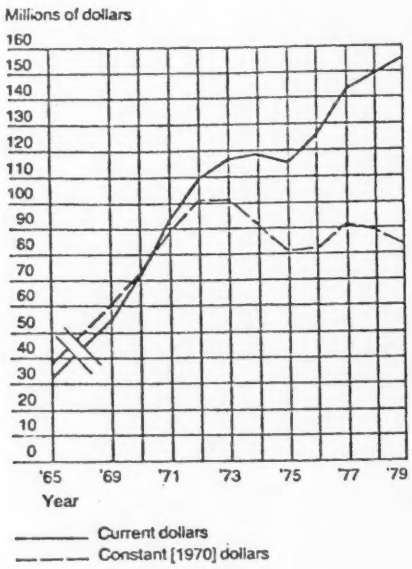
Basic research from a wide range of scientific disciplines is the source of fundamental knowledge needed to supply leads for development of contraceptive methods by improving knowledge about reproductive processes. Mission-oriented research generally refers to efforts aimed at accomplishing a specific contraceptive end; examples include a means of arresting spermatogenesis, or a luteolytic agent. The direct source of new products and technologies is applied R&D, which endeavors to utilize fundamental knowledge and understanding to develop new materials, new techniques and new processes in order to create a new product. Product introduction converts a newly developed prototype product into a widely available manufactured item. This final step comprises product acceptability and marketing studies, design and engineering of production plants, pilot trials of manufacture, package design, regulatory filings, establishment of distribution channels and other activities designed to ensure local introduction and use of new products.

Reproductive and contraceptive research did not benefit from the rapid expansion of funding for biomedical research by the governments of the United States and other industrial nations in the two decades after World War II, largely because of the traditional taboos against the study of sex and reproduction and the moral and religious controversies over government involvement in birth control. Indeed, until 1959, the U.S. National Institutes of Health were prohibited from supporting research having any explicit relationship to birth control. During the 1950s, biomedical research in the field of reproduction was largely funded by two major private foundations--Ford and Rockefeller--and a few individual philanthropists. The oral contraceptive was developed with the support of private philanthropy and some sectors of the pharmaceutical industry. In 1967, an Office of Population was established within the U.S. Agency for International Development (AID). The Center for Population Research (CPR), now the major source of funds worldwide for reproduction and contraceptive research, was established as part of the U.S. National Institute of Child Health and Human Development in 1968. In 1969, the United Nations Fund for Population Activities (UNFPA) began; recently, UNFPA has begun to make small expenditures for contraceptive development

through annual contributions to the Human Reproduction Program of the World Health Organization (WHO). During the late 1960s, other developed countries--Britain, Canada, France, Sweden and West Germany--also began to fund reproductive and contraceptive research. Smaller efforts--most of them supported by international assistance agencies--were undertaken in some developing countries; the largest of these was in India.

The result of this increased concern can be seen in Figure 1. Funding for all aspects of reproductive and contraceptive research rose rapidly, from an estimated $31 million in 1965 to $117 million in 1973. Although this total research budget continued to climb in current dollars to an estimated $155 million in 1979, expenditures corrected for inflation had peaked in 1973. The U.S. government contributions for reproductive research have been increasing since the mid-1970s in constant as well as current dollars and represent nearly half the world total, while the investment of private philanthropies has declined somewhat and contributions of other governments apparently have not grown. The investment of the private pharmaceutical companies is believed to have plateaued in the late 1970s at about $14 million and apparently has declined in constant-dollar terms because of increased concern about the profitability of investment in research into new methods.

Figure 1. WORLDWIDE EXPENDITURES FOR REPRODUCTIVE RESEARCH 1965-1979



We will now discuss potential development of four contraceptive methods, any one of which, the authors believe, would significantly

increase current use. Combined, the methods could revolutionize contraceptive practice in developing countries.

I. Nonsurgical Female Sterilization

Current efforts to develop a nonsurgical method of female tubal sterilization involve the delivery of a sclerosing agent to the uterotubal opening via the vaginal cervix and uterus. By irritating the tissue of the fallopian tube, the substance causes the lumen of the tube to close from scarring. Ideally, the method could be delivered by paramedical personnel trained to insert IUDs, and delivery could be accomplished without pain, using local anesthesia. Effectiveness should be as high as that experienced with current methods of surgical sterilization. These methods would need to be nontoxic. Sterilization would be irreversible.

Status of research. Two substances and various means of delivery are now under investigation. Methylcyanoacrylate and quinicrine hydrochloride are now being used in clinical trials. The former is a widely used "tissue glue" that polymerizes in the tube, forming a plug to which the tissue adheres. The plug eventually biodegrades, leaving behind scar tissue which permanently closes the tube.

Quinicrine is a drug that has been used for treatment of malaria. When placed in the uterine cavity in the form of crystalline pellets or in a thick suspension, the chemical enters the oviducts initiating a scarring process that results in tubal closure. A potentially more effective way of introducing the quinicrine into the tubal opening, by attaching pellets of the drug to the transverse arms or fundal portion of an IUD, is being tested. In this procedure, the pellets are held in place for several days, providing a longer time for the drug to penetrate the tubes.

Both of these sclerosing agents, and several instillation procedures, are being tested in small clinical trials. Long-term followup of subjects is necessary to observe the effective duration on closure as well as such possible problems as increased risk of ectopic pregnancy. At present, the methylcyanoacrylate seems to be only 80 percent effective in completely closing the tubes on just one application. It is believed that with two applications, an effectiveness rate of 95 percent could be achieved. Efforts are being made to improve delivery. Modifications of the instrument used for instillation are being investigated that would reduce its cost and improve its performance.

Advantages. A nonsurgical method would involve far less pain and discomfort than do sterilization methods now in use. The user would not require hospitalization nor the unavoidable long recovery period necessary with surgical methods. The risk of morbidity and mortality associated with general anesthesia (used with some current methods) and opening the abdomen to reach the fallopian tubes should be eliminated. The cost of nonsurgical sterilization should be lower than that of minilaparotomy, and much lower

than that of laparoscopic sterilization. A major advantage of the method is the possibility that it could be delivered by paramedical personnel.

Drawbacks. It is possible that none of the agents currently under investigation will be capable of yielding effectiveness rates as high as those of surgical techniques because of incomplete closure or recanalization of the damaged section of the tube. This could mean that up to five percent of women who undergo the procedure would get pregnant. In addition, there may be rare complications associated with the chemicals used. Even the simplest approaches currently under study require operators with fairly high levels of technical skill and will probably require a clinic setting where sterile instruments are available.

II. A Reversible Method for Men

There are three approaches to male contraception: stopping the production of sperm; blocking the transport of sperm during intercourse; and affecting the quality of sperm so that they are incapable of fertilization. All male methods currently in use--vasectomy, the condom and withdrawal--are based on the second approach. What is being sought by contraceptive R&D organizations is a highly effective, reversible, self-administered, coitus-independent contraceptive that does not interfere with libido, is free from dangerous side effects, is inexpensive and is easy to distribute.

Status of research. It has long been known that massive doses of steroids will usually cause infertility in men by shutting down sperm production. Until recently, investigations into a possible male method have concentrated on different combinations of various steroidal hormones.

Another promising method for arresting spermatogenesis has recently entered early clinical trials: a chemical analog of the brain hormone--luteinizing hormone-releasing hormone (LHRH). The effects of this decapeptide, which stops sperm production in male rats, is being carefully observed in a small group of volunteer men. There has probably not been sufficient basic research to understand the effects of LHRH on the reproductive processes. If the analogs now in limited clinical trial prove successful, it will still be at least seven years and, if new analogs are needed, possibly 10-15 years, before they become generally available.

Another method under investigation that is apparently highly effective in stopping sperm production is gossypol, a derivative of cottonseed oil. Chinese scientists claim to have administered gossypol pills for at least six months to some 4,000 men, with an efficacy rate of 99 percent. Some of the men have been on the pills for more than six years. The pills are taken daily for about two months until sperm are no longer observed, and then are taken weekly to maintain infertility. Fertility generally returns to normal in about three months after discontinuation of treatment. Gossypol apparently works by incapacitating the sperm-producing cells.

Several research organizations outside China are investigating possible long-term adverse side effects. At least three to five years will be required for widespread human testing in other countries after current toxicology studies are completed. If side effects prove to be significant, a gossypol analog synthesis and screening program will be required to discover safe but effective compounds, and it would be 10-15 years before a marketable product would be generally available.

Little progress has been reported in finding an acceptable method which would cause infertility by inhibiting sperm maturation or motility. Important mission-oriented research remains to be done on sperm maturation and capacitation in order to make this type of research truly productive.

Some scientists are also intrigued with the potential of inhibin as a male contraceptive. If this naturally-occuring substance could be structurally identified and synthesized, it is thought, it could be effective in suppressing the secretion of follicle-stimulating hormone (FSH), necessary for normal spermatogenesis. However, considerable mission-oriented research would have to be undertaken before inhibin could be considered a potential male contraceptive.

Advantages. Based on clinical experience to date, it is thought that the LHRH analogs will have few systemic side effects. In addition to being effective as a contraceptive, gossypol should have little or no effect on libido, since it does not seem to affect the cells producing the male sex hormone, testosterone. The raw material is widely available, and the product should be relatively inexpensive. Neither LHRH nor gossypol would require clinical or surgical facilities, and both should be relatively easy to distribute.

Drawbacks. In addition to their contraceptive effect, the steroids reduce testosterone synthesis, sometimes resulting in loss of libido and development of female secondary sexual characteristics (such as enlarged breasts). The method is of unreliable effectiveness, as sperm counts are not reduced to zero in all men. In addition, testosterone has to be administered by injection at fairly frequent intervals, requiring clinical facilities; and recovery of fertility takes up to six months in some subjects.

LHRH analogs may decrease the synthesis of testosterone (and therefore libido). Both LHRH and gossypol would probably require one to two months of daily administration before they completely suppress sperm production. At present, the reversibility of the effects of these drugs on the testes is not well understood. Obviously, if there is permanent damage to the sperm-producing cells, neither product would be approved as a contraceptive. At any rate, it is likely that a very long recovery period would be required for any method that blocked sperm production.

Gossypol may well have some adverse side effect in humans since it is known to be highly toxic in some animal species.

III. An Antipregnancy Vaccine

Contraception could be achieved by vaccination with protein antigens specific to pregnancy or to an organ involved in the reproduction process. Circulating antibodies would interfere with ovulation, corpus luteum function, fertilization, early implantation, or maintainance of pregnancy, depending on the antigen selected. Ideally, the method would be administered in one injection. After a period of months required for the antibody titers to build up to sufficient levels, contraceptive effectiveness would be maintained for one to three years. Such an immunological method should be reversible with declining antibody titers, but effective contraception could be renewed by means of a single booster vaccination administered in the final months of the effective period.

Status of research. The principle of antibody reaction in response to an injection of a protein derived from the beta chain of human chorionic gonadotropin (hCG) has been shown in human clinical trials. However, the effectiveness of the antibodies and the safety of the method have not yet been demonstrated.

Two major approaches have been utilized: The first involved immunizations with an antigen consisting of highly purified beta-hCG chemically linked with tetanus toxoid. Menstruation and ovulation continued normally, but some pregnancies ensued. A more active antigen appears to be needed.

Theoretically, one problem with this approach is the possibility that cross-reactive antibodies could neutralize other similar pituitary hormones, stopping the function of the target organ permanently. Although no such cross-reactivity was found in experiments with women, some researchers have sought to protect against this possible problem; their work has constituted the second major approach to an antipregnancy vaccine. Those researchers have concentrated on finding a vaccine against a unique fragment of the beta-hCG chain which does not cross-react. However, the difficulty of finding a powerful enough adjuvant to create an effective antibody reaction is even greater when dealing with such a small fragment than when the whole beta-hCG molecule is the target.

Investigation at a much more basic level is also proceeding on antigens derived from the zona pellucida, the outer coating of the ovum at the time of ovulation and before implantation. Such antibodies are thought to form a deposit on the outer surface of the zona, which prevents sperm penetration and thus inhibits fertilization. Such antigens have not yet been isolated in pure form, however. Sperm antigens are also being studied, but so far they have proved relatively ineffective in animal tests. Given the very early stage of R&D in this area, a minimum of 10-15

years of sustained, high-priority effort will be needed to produce a vaccine using either the beta-hCG or one of the other approaches.

Advantages. Vaccination is a universally appreciated and understood medical intervention. The method is unlikely to require any special facilities for delivery, since in most countries there are already facilities for vaccination programs, and paramedical personnel and barefoot doctors are already trained to give injections. Effectiveness should be high, and the antifertility effect would be limited to one event in the reproductive process; short-term side effects should be minimal. The eventual cost would probably be similar to that for other types of vaccination offered by public-health programs in developing countries.

Drawbacks. Long intervals of effectiveness imply a relatively long time period for return to fertility, which might in itself reduce acceptability among some women. During the initial period--about three months--when antibody titers were being built up, and in the final months of declining titers, another method of contraception would be needed. Although paramedical personnel could administer the injections, they would have to be specially trained to deal with allergic reactions inevitable among a small percentage of recipients. What is more, a vaccination program requiring periodic inoculations is known to be difficult to mount and maintain in some developing-country settings.

IV. A Postpartum IUD

An intrauterine device that would be retained when it is inserted immediately after the placenta is delivered could reach all women who have assisted deliveries. Conventional IUDs inserted during the postpartum period are likely to be expelled about three times more often then when they are inserted during the menstrual cycle. The high rate of expulsion occurs because the postpartum uterus is in the process of contracting to its prepregnancy size. Unless the IUD can be anchored high in the uterine fundus, uterine contractions can easily displace it. Ideally, such a device would be effective over a woman's entire reproductive lifespan, and would need certainly to be effective without replacement for several years. Insertion by a specially trained non-physician birth attendant should be feasible. At least a 98-99 percent effectiveness rate should be obtained.

Status of research. Several types of postpartum devices are currently being investigated. One is simply a Lippes loop with three surgical sutures attached to the uppermost curve. The sutures anchor into the fundus of the uterus and slowly dissolve, so that by the time uterine involution is complete, the sutures have disappeared, and a conventional IUD remains in place. A second device, a modification of the Nova-T, a copper-bearing device, has plastic flanges near the base of the stem. If placed high in the fundus of the uterus, the flanges brace against the walls of the involuting uterus, preventing downward displacement. The first device has

achieved encouragingly low expulsion rates in limited clinical trials. Field trials to determine effectiveness of both devices will be initiated shortly and if several conditions are met, a postpartum device could become widely available in less than five years.

Advantages. If a traditional birth attendant could be trained to insert such a device properly at the time of delivery, the method could reach large numbers of women in developing countries at a time when motivation to avoid pregnancy is generally high. Unlike the pill, IUDs do not interfere with lactation, and they do not introduce drugs or steroids into the breast milk. Many women in the developing world are not routinely seen by medical or paramedical personnel except when giving birth.

Drawbacks. The postpartum IUD would possess the same side effects associated with conventional devices--notably, disturbing menstrual bleeding patterns, pain and pelvic inflammatory disease and, possibly, subsequent infertility. Indeed, these devices may tend to increase postpartum bleeding, spotting and cramps, and special care would be needed to prevent infection. For women who deliver in hospitals, skilled medical services would presumably be available, but traditional birth assistants would need to have special training to insert these IUDs.

Other Possibilities

Scientists have long been interested in developing a pill, liquid, nasal spray or vaginal tampon that could be self-administered at the expected time of menses to induce menstruation and evacuation of the uterus. A desirable agent for this purpose would have few side effects and would totally evacuate the uterus. However, this possibility was excluded from consideration here as it is not strictly speaking a contraceptive method.

What Can Be Done?

The fact that world population growth rates have begun to slow in a number of countries of Asia and Latin America has led to complacency among some policy-makers that the "population problem" has been solved, and that no major initiatives, such as the development of a new contraceptive technology, are needed. Many of them have become convinced that the only solution lies in more efficient organization of services and the initiation of community pressures and incentives. However, the demonstration of receptivity to family planning efforts in countries around the world is a persuasive argument for assigning high priority to research in contraceptive development. There is no single "technological fix" for problems engendered by population growth. But new methods of fertility control that better meet individual needs and preferences and that are effective, safe and require less costly and sophisticated delivery systems

than those now available can accelerate fertility declines now taking place, as well as help initiate them in places and among couples where current methods are inappropriate.

There is a good chance that some of the methods described here could be made available to the public within the next decade if public-sector funding for contraceptive development were increased by some four times, if donors made that funding available on a secure, long-term basis, if there were improved coordination and planning by donors and research programs, if there were more reasonable requirements by regulatory agencies and if there were more effective harnessing of the potential of industry. We are proposing a program of mission-oriented research involving the simultaneous pursuit of various technological leads to achieve a particular type of method (such as a male pill or an antipregnancy vaccine). This would certainly require--in addition to greatly increased funding--far greater coordination among developers and donors than now exists, in order to choose the methods for research concentration and to allocate the various approaches to those organizations that are best suited to pursue them. As funds become limited, this consideration becomes even more important.

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Signs of Change in Mortality Trends—Is Progress Slowing?

Davidson R. Gwatkin

[The extraordinarily fast rates of decrease in death rates in both developing and industrial countries after World War II have begun to show signs of slowing. The diversity among nations appears to be increasing. The evidence on changes is discussed, as are their possible causes and implications.]

Compared to the attention given fertility changes in the developing world, recent mortality trends have recieved little notice. Yet there are indications that developing world mortality patterns are also evolving in ways that are potentially important for human welfare. In particular, recent findings suggest that the remarkably rapid rates of mortality decline that have prevailed since World War II have begun to falter, to give way to a diverse, ambiguous situation marked by unexpected slowdowns in the pace of health improvements observed in many large areas of the developing world.

The Era of Rapid Mortality Decline

Widespread good health and low mortality are recent, principally twentieth century phenomena. In 1900, a typical newborn infant exposed through its lifetime to the conditions then existing in the world as a whole could expect to live some 30 years. Now, three-quarters of a century later, the prospect is for a lifespan approaching 60 years, almost twice as long. Leaving aside relatively limited periods of unusual disaster, life expectancy at birth has rarely been below 20 years. Thus, almost three-quarters of the total increase of longevity in recorded human history has been concentrated in the past 75 or 80 years. Until about 1960,

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the dominant trend was generally one of accelerating progress. This took the form of three waves, each reaching greater heights than that preceding it, culminating in extraordinarily rapid rates of improvement, especially in the world's poorest regions, during the period's later stages.

The first wave originated in Western Europe in the late 1800s and spread to the United States soon thereafter. Except for a pause during the interwar years, presumably resulting from the Great Depression, the rate of improvement in Western European life expectancy increased steadily from the late nineteenth century into the 1950s. From the virtual stagnation recorded between 1840 and 1850, the annual increase in life expectancy rose to 0.20 years and in 1880-90 and 0.40 years in 1910-20. [As an example of the average annual rate of increase: suppose life expectancy rises from 52 to 54 years in a period of six years. The increase is 2.0 years; the rate of increase per year is 2.0 ÷ 6 = 0.33 years.] Then, after a fall to 0.29 years during the 1930s, the period from 1940 to approximately 1955 saw an annual increment of 0.43 years. In the United States, the rate of life expectancy increase rose steadily from the turn of the century to 0.56 years annually during the 1920s, fell to 0.32 years annually in the 1930s, and then recovered to 0.53 years annually during the following decade.

Shortly after the acceleration of mortality decline in the West, the second wave of even more rapid progress began to be recorded in Eastern and Southern Europe. By the 1920s, life expectancy in the nine countries of that region for which data are available was rising by over 0.50 years annually. After a virtual cessation of progress in the late 1930s and early 1940s, the region registered a still more rapid average annual gain of over 1.0 years during the following decade, a pace notably faster than the most rapid rate of gain experienced in Western Europe or the United States. By the 1960s, Eastern and Southern Europe's rapid progress had nearly eliminated the traditional large differences between life expectancies there and in Northern and Western Europe.

The third wave, in the developing countries, appeared shortly after World War II. Such evidence as is available suggests that significant mortality decline had begun earlier in at least some areas: soon after the turn of the century in parts of Latin America, and during the 1920s in India, for example. But such increases were modest compared with those that came later, for soon after World War II annual gains in life expectancy averaging over a year were recorded for periods of up to a decade in such diverse places as Taiwan, Malaysia, Sri Lanka, Mauritius, Jamaica, and Mexico. In Mauritius and Sri Lanka, the increase exceeded two years annually: life expectancy rose from 33.0 to 51.5 years between 1943/46 and 1951/53 in Mauritius and from 42.7 years in 1946 to 56.7 years in 1953 in Sri Lanka. Many

developing countries recorded life expectancy gains three or more times as large as those achieved in Western Europe at a comparable stage in its mortality transition.

As a result of such waves of acceleration, life expectancy appears to have been rising at a record or near-record pace in most parts of the world during the decade or so immediately following the end of World War II. By far the most impressive of the increases were those occurring in the developing countries. Not only were they clearly faster than in Europe and the United States, they were occurring in settings where life expectancies were 15 to 30 years below those in Europe and the United States. Such rapid progress coming at such low initial levels of life expectancy was, as many commentators noted, quite without precedent in history.

Also, unlike the rapid developed-country mortality declines, which were recognized as probably unsustainable, these developing world increases seemed likely to continue for some time into the future. Life expectancy in the advanced nations was already high by 1950, with most deaths occurring at older ages, caused by relatively intractable degenerative diseases; and as a result, the rapid life expectancy increases of the preceding century were widely considered to be unrepeatable. But the situation in the developing world was different: life expectancies were still low; the introduction of public health and disease control methods suggested that economic and social misery need no longer pose a significant barrier to sharp rises in survival probabilities; and the unprecedentedly rapid mortality gains in those leading developing countries with reliable data seemed to reinforce the sense that comparably rapid gains ought to be achievable in regions where mortality transitions were just beginning. Thus, while an eventual slowdown in the pace of mortality decline was recognized as inevitable, and while there was some concern about the longer range mortality implications of accelerating population growth, by and large the outlook for the years immediately ahead seemed promising. The authors of the comprehensive and authoritative 1962 United Nations report on mortality suggested that: "It may not be too much to hope that, within a decade or two, the vast majority of the world's peoples will have an expectation of life at birth of 65 years or more." In 1963, as shown in Table 1, the UN projections foresaw an increase in the pace of life expectancy improvement in the less developed regions from the 0.50 years recorded annually between 1960/65 and 1965/70 to 0.58 years annually between 1965/70 and 1970/75.

Signs of Slowing Progress and Increasing Diversity

As will soon become clear, data problems render very difficult any precise statement about what has recently been happening to mortality trends, especially in the developing world. But the figures

Table 1
Anticipated and Reported Rates of Life Expectancy Increase: Less Developed Regions, 1960/65–65/70 and 1965/70–70/75

	Average Annual Increase, 1960/65–65/70 (years)	Average Annual Increase, 1965/70–70/75 (years)
As anticipated in 1968[a]	0.50	0.58
As reported in 1978[b]	0.52	0.40

[a]Medium variant figures calculated from data presented in United Nations, Department of Economic and Social Affairs, *World Population Prospects as Assessed in 1968* (ST/SOA/Series A/53, "Population Studies, No. 53"; New York: United Nations, 1973), p. 141.
[b]Calculated from data presented in United Nations, Department of International Social and Economic Affairs, Population Division, *World Population Trends and Prospects by Country, 1950–2000: Summary Report of the 1978 Assessment* (ST/ESA/SER. R/33), 1979, p. 28. (Figures are arithmetic averages of male and female life expectancies.)

and analyses that exist are adequate to indicate rather clearly that the continuing accelerations in mortality decline that marked the period from 1900 to the mid-1960s have largely come to an end. They appear to have been succeeded by slower progress and increasing diversity, recorded both in those areas where slowdowns had been anticipated and also in many regions where rapid progress had been expected to continue.

Recent trends can be assessed with greatest confidence in the developed countries, where, as indicated, a deceleration had been expected. In the Western European countries referred to earlier, for example, life expectancy increased at around 0.11 years annually during the 1960s, down from the annual increase of 0.40-0.50 years of the late 1940s and early 1950s; the pace of improvement in the United States was 0.24 years annually between 1960 and 1970, less than half the 0.53-0.55 years annually of the earlier decades; the nine Eastern and Southern European countries advanced at an annual rate of 0.20 years, down from the previous pace of over one year annually.

Elsewhere, while progress has continued, the available estimates provide little basis for believing that the rapid post-World War II pace of developing world mortality decline was maintained, and they provide numerous indications of decelerating progress in many large areas and a resulting failure to achieve the life expectancy levels that had earlier seemed within reach. According to the most recent (1978) UN estimates, for example, only about 30 percent of the world's population--and only 2-3 percent of the population of the developing

nations--lived in countries with an average life expectancy of 65 years or more, one decade after the 1962 statement cited. As Table 1 indicates, the earlier-anticipated acceleration in the average annual increase in the less developed regions from 0.50 to 0.58 years between 1960/65-1965/70 and 1965/70-1970/75 did not materialize. Instead, there was a slowing from 0.52 to 0.40 years. According to Table 2, life expectancy in both the more and the less developed regions was increasing by 0.6-0.7 years annually in the mid-1950s. By the early 1970s, the reported annual improvements were only around 0.15-0.20 years in the more developed countries, and 0.40 years in the less developed nations. While the figures represent no more than general orders of magnitude, it is notable that none of the three major regions of the developing world--Asia, Africa, and Latin America--recorded an increase in the rate of progress at any time later than the late 1950s or early 1960s. The dominant trend, rather, was a steady decline.

Table 2
Levels and Rates of Increase in Life Expectancy by Major World Regions, 1950/55–1970/75

Life Expectancy at Birth (in years)

Region	1950/55	1955/60	1960/65	1965/70	1970/75
World	47.4	50.2	52.7	54.5	56.2
More Developed Regions	65.2	68.3	69.8	70.4	71.2
Less Developed Regions	42.6	45.8	48.8	51.4	53.4
Africa	37.6	39.8	42.2	44.5	46.5
Latin America	52.0	55.0	57.3	59.4	61.3
Asia	43.4	46.9	50.4	53.4	56.0

Average Annual Increase in Life Expectancy at Birth (in years)

Region	1950/55–1955/60	1955/60–1960/65	1960/65–1965/70	1965/70–1970/75
World	0.56	0.50	0.36	0.34
More Developed Regions	0.62	0 30	0.12	0.16
Less Developed Regions	0.64	0.60	0.52	0.40
Africa	0.44	0.48	0.46	0.40
Latin America	0.60	0.46	0.42	0.38
Asia	0.70	0.70	0.60	0.52

SOURCE: Calculated from data presented in United Nations, Department of International Social and Economic Affairs, Population Division, *World Population Trends and Prospects by Country, 1950–2000: Summary Report of the 1978 Assessment* (ST/ESA/SER. R/33), 1979, pp. 62-66. (Figures are arithmetic averages of male and female life expectancies. Asia life expectancies are the averages, weighted by population, of United Nations East and South Asia figures.)

These UN estimates also suggest a weakening in the tendency toward the convergence among the world's countries and regions that had earlier been a noteworthy feature of mortality trends. The life expectancy gap between the more and less developed regions of the world was reduced by only a little more than one year between 1965/70 and 1970/75, compared with two years during the preceding five-year period. More distinct is the absence of any tendency toward a reduction in the life expectancy gap between the less and more advanced nations within the world's developing regions during the past quarter-century, because laggard as well as advanced countries were affected by the slowed pace of progress.

[Note: A section omitted from this extract examines in detail population data from other sources for countries in the less developed regions. These figures generally show declines in the rates of increase in life expectancy comparable to those in the UN figures.]

Possible Causes

It seems fairly clear that other reports available for individual regions and countries point to changes in developing-world mortality trends at least as significant as those indicated by the UN estimates of Table 2. Equally clear, though, are the illustrations that such individual country and regional studies provide of the limited reliability of developing country mortality data and of the resulting problems that arise in attempting to assess developing country mortality trends on the basis of the available demographic data alone. No mortality data of even moderate reliability exist for China, the world's most populous country, or for Sub-Saharan Africa. In most cases, the information available consists principally of estimates by demographers applying their statistical skills and professional judgments to bits and pieces of information drawn from a wide variety of sources. It is clear, certainly, that estimates prepared in this way are much more than simply guesses drawn out of thin air; and one cannot dismiss as worthless the best demographic judgment available. But still, the fact remains that any discussion of developing world mortality levels and trends unavoidably deals more with professional judgment than with firm data.

In view of such uncertainties, it becomes particularly important to assess the plausibility of the figures reported in the demographic literature by comparing them with what is known about recent developments concerning factors thought to be responsible for mortality trends. On the whole, the evidence indicates that in light of what is known about recent medical, social, and economic progress, one might well anticipate slowdowns in the rapid mortality declines found earlier in the developing world.

Public health developments. A notable aspect of recent developments in public health and medical care programs has been what many authorities view as a marked decline in their capacity to deal with evolving disease

problems of the developing world. In particular, the diarrhea, pneumonia, and malnutrition that now predominate in much of the developing world appear to be posing a significantly more difficult challenge to medical and health programs than the communicable diseases prominent in earlier years. This provides a basis for suspecting significant decrease in the contribution of medical and health programs to mortality decline.

Although the rapid mortality decreases had begun in some areas before the advent of effective medical approaches, the marked progress recorded during the years immediately following World War II appears to have owed a great deal to the new generation of improved medical technology that became available at that time. The postwar period is well known for the first widespread introduction in the West as well as the developing world of the modern antibiotics and insecticides whose development had been hastened to support World War II military operations, and the markedly improved drugs for the treatment of tuberculosis which first came into widespread use in the late 1940s. And it is possible to trace impressive accelerations in mortality decline in specific countries to the time when such new technologies became available.

In the advanced nations, examples that come readily to mind include the rapid fall in mortality concurrent with the introduction of antibiotics in the United States; the marked acceleration in the decline of mortality from tuberculosis in New Zealand, England and Wales, and New York City following the introduction of new drugs for treating tuberculosis in 1947; and the elimination of deaths caused by malaria in previously endemic Italy by the close of a 1945-58 insecticide-based drive. In the developing world, the examples are even more numerous, and the gains appear to have been at least equally great. On the basis of careful econometric investigation, Samuel Preston has concluded that factors other than social and economic development--notably health measures--could be credited with about one-half of the 18-year increase in developing world life expectancy between 1935-40 and 1965-70. While environmental improvements--such as increases in protected household water supplies and improved sanitary facilities--presumably played a role, gains against those infectious diseases most amenable to direct treatment or control through technological means were particularly significant. Malaria control alone, for example, has been associated with a five-to-six point fall in the Indian crude death rate and with almost a quarter of the improvement in Sri Lankan longevity. Smallpox is thought to have been eradicated; mortality from tuberculosis is now notably lower in the developing world than it was in the West when overall mortality levels were comparable; and, although the data are uncertain, there appears to have been significant progress against some other types of airborne respiratory infections as a result of the combined impact of antibiotic therapy and improved living standards.

As the number of deaths attributable to these diseases has declined, they have been replaced as leading causes of developing world mortality by

by less specific gastrointestinal and respiratory infections that are much more difficult for standard Western medical technology to handle effectively. Infectious and parasitic diseases, Samuel Preston and Verne Nelson have shown, have made progressively smaller contributions to overall mortality levels, with diarrheal diseases rising (in relative terms) to replace them. As a result, they report, mortality from diarrhea in the developing world is typically twice to three times as high as it was in the West at a time when overall mortality levels were similar.

During the 1960s physician- and clinic-based medical services came increasingly to replace campaigns against the by then largely eliminated communicable diseases as the mainstays of developing country health programs. In the view of most observers these medical service units have thus far been unable to handle the newly dominant diseases effectively. For example, John Bryant's influential 1969 volume on health care in developing countries concluded:

> The great weapons of modern medicine are aimed at the pathophysiology of disease and its susceptivity to pharmaceutical, immunological, or surgical attack. Health services are designed to deliver these weapons mainly through the hands of doctors. The dismal fact is that the great killers of children--diarrhea, pneumonia, malnutrition--are beyond the reach of these weapons. If children sick with these diseases reach the physician, there are sharp limits to what he can do. Diarrhea and pneumonia are often not affected by antibiotics, and the frequent presence of malnutrition makes even supportive therapy difficult or futile. And even these interventions by the physician, whether or not they are therapeutically effective, are only sporadic ripples in a running tide of disease. We are speaking of societies in which, at any given time, a third of the children may have diarrhea and more than that may be malnourished. Their lives are saturated with the causes--poverty, crowding, ignorance, poor ventilation, filth, flies. (Health and the Developing World, Cornell University Press, 1969, p. 39.)

Social and Economic Trends. Inimical as such trends in the health sector obviously are for continued rapid mortality decline in the developing world, further rapid progress could nonetheless have taken place had there been an offsetting acceleration in the pace of social and economic progress. There is little indication, though, that any such acceleration has occurred. More prevalent are suggestions of increasing diversification and slowdowns within the developing world with respect to a number of aspects of social and economic progress generally considered most directly relevant for mortality decline.

The World Bank's *World Development Report* points to only a minor decrease from 3.1 percent to 2.9 percent in the annual growth of real per

capita gross national product between 1960/70 and 1970/80 for 90 developing countries. But within this fairly steady pace of development, the records of different countries or groups of countries varied greatly. While the growth of per capita GNP in the middle-income developing countries of East Asia and the Pacific rose from 4.9 to 5.6 percent annually, that of the low-income oil-importing nations of Sub-Saharan Africa declined from 1.6 percent to 0.2 percent. During 1960-78, the economies of those 52 countries categorized as middle income by the World Bank grew at an average annual rate of 3.4 percent annually, twice the 1.7 percent of the 38 lower income countries; and the gap between the two increased, from US$500 to over $1,000.

With respect to other aspects of development that are relevant for mortality, the trend figures suggest the onset of overall decelerations sometime during the 1960s. Food production in the developing world as a whole, for example, rose by about 40 percent during the 1950s and per capita food production increased by 11-12 percent. In the following decade, food production increased somewhat more slowly, by about 30 percent, while per capita food production increased only about three percent with a more rapid population growth. The Fourth World Survey of the Food and Agriculture Organization of the UN found that in the developing countries "during the period 1970 to 1976 the growth rate of total food production slowed down to 2.7 percent and to only 0.3 percent on a per caput basis... Indeed, during the early 1970s, the per caput increase in the developing countries has shrunk to an insignificant level." While recent years appear to have seen at least some recovery, developing country per capita food production in 1978 was only about 3 percent higher than in 1970--only around 1 percent higher when China is excluded.

In addition to such developments of world relevance, there are several instances where severe local economic and political difficulties enhance the credibility of reports of the altered mortality trends in particular countries. Probably the most conspicuous example is the series of disasters that beset Bangladesh: the 1970 cyclone that devastated the country, the severe civil disorders associated with that country's transition to independence in 1971 and 1972, the unusually difficult agricultural years that followed immediately thereafter. In India there was a 5-7 percent decline in per capita calorie and protein availability between the early 1960s and the mid-1970s, along with the withering of the antimalaria campaign which had coincided with the particularly rapid mortality gains of the late 1950s and early 1960s (the reported number of malaria cases rose from 50,000 in 1961 to nearly 5 million by 1975). The years of stagnation or rises in mortality in Argentina and Uruguay were those that were marked by severe political and associated economic troubles. At the other end of the scale, unusually high levels of life expectancy achieved by such developing countries as Hong Kong, Taiwan, and Singapore do not seem as surprising as they otherwise might when it is recognized that all three were among the top four economic performers according to the World Bank.

Neither such impressions of individual countries nor what was said earlier about medical, social, and economic trends in the developing world as a whole are in themselves conclusive, of course. But even though only broadly suggestive, they are more than sufficient to provide reasonable support to the altered trends reported by recent mortality data. The slowdowns in progress against mortality would be logical concomitants of reduced power of existing medical technology and of slowed social progress. And similarly, increasing diversity in mortality patterns would seem natural in light of the widely different rates of economic and social progress being reported.

Approach of maximum longevity. It would be reasonable to expect some slowing of progress as life expectancy begins to approach a level of around 75 years, which, at the present state of human knowledge, lies close to a natural limit established by physiological degenerative processes. This is clearly relevant to trends in the developed countries, and also in a few situations like Hong Kong, Singapore, and Taiwan. But one cannot accept it as the principal explanation of changes observed elsewhere. This is because high-mortality countries as well as low-mortality countries seem to be experiencing a comparable slowing of progress. For example, Arriaga and Heligman found a sharp slowing not only in Venezuela, with a life expectancy of 63 years, but also in Guatemala and El Salvador, with life expectancies of 49 and 56 years; and the slowdowns in Asia have affected India and Bangladesh, where life expectancies have yet to reach 50 years, as well as Sri Lanka, with a life expectancy of over 60 years.

The End of an Era?

In brief, the mortality data available, supplemented by what is known about related medical, social, and economic trends, suggest that the era of unusually rapid developing country mortality declines has at least temporarily come to an end. Overall, progress continues, but at a slowing rate that, while still far from insignificant, had by the early 1970s reached a level more reminiscent of prewar Western Europe than of the developing world in the 1950s. While some countries have continued to record impressive gains, stagnating and even upward mortality trends are reported in others.

Whether such altered trends are harbingers of still less fortunate future developments remains to be seen. Perhaps the passage of time will reveal them to have been so, but other scenarios are certainly possible. Even under the worst possible legitimate interpretation of the imprecise data available, it is clear that the slowdowns have not thus far affected all of the developing world. The continuing rapid progress in a number of developed countries also suggests that early slowdowns are far from inevitable. At least some of the particularly severe setbacks discussed earlier appear due partly to conditions that are not likely to endure. Even slowdowns that may result from more fundamental decelerations

in social, medical, and economic development are not necessarily immutable. The inappropriateness of conventional health care strategies has become increasingly recognized in recent years, and potentially promising alternative approaches are now under development. Food production poses a more formidable challenge, perhaps, but as numerous studies have shown, the potential for improving yields in the developing countries is very large. And so on. One cannot conclude from recent history that many or most developing world countries are inevitably doomed to Malthusian perdition. Yet neither would it be justified simply to shrug away the change reported as nothing more than statistical artifacts or temporary aberrations of no significance. Certainly, many of the figures cited are not beyond challenge: but there are too many of them, from too many sources, to be ignored. Taken together, they strongly suggest that the pace of health improvements has become more fragile and uncertain, as likely to slow or halt altoghether in response to unfortunate political, economic or climatic epidodes, as it is to continue along the seemingly automatic downward trajectory of the earlier part of the post-World War II period.

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1717 Massachusetts Ave. N.W.
Washington, D.C. 20036
U.S.A.

CLEAN WATER

International Drinking Water and Sanitation Decade

The history of the International Drinking Water Supply and Sanitation Decade began in 1976 at Habitat (the United Nations Conference on Human Settlements), which recommended that all people should have access to safe water and hygienic waste disposal by 1990. The U.N. Water Conference at Mar del Plata, Argentina in 1977 reaffirmed this Habitat objective and, in its Plan of Action, recommended that the period 1981-1990 be designated the International Drinking Water Supply and Sanitation Decade, devoted to promoting and implementing national plans for drinking water and sanitation. United Nations agencies as well as national and private aid agencies have made commitments to participation in the Decade's program.

A part of the contribution of the U.S. Agency for International Development (AID) to the Decade has been to add Project WASH (Water And Sanitation for Health) to its $200 million a year program in this field. The project will provide AID services in rural and urban-fringe water supply and sanitation to host country governments, to other international aid agencies, to private voluntary organizations and to other organizations. The WASH project assists in the following areas:

- General Technical Assistance
- Technology Transfer
- Manpower Development and Training
- Information Support

For further information on the activities and functions of WASH contact:

Information Director
WASH Project Coordination
and Information Center
Room 1002
1611 North Kent Street
Arlington, Va. 22209 USA

On the preceding page: The pump symbolizes the United Nations Water and Sanitation Decade's attempt to provide safe drinking water for the world by 1990. The U.N. symbol for the Decade is the water drop with a human figure inside it. (Graphics: Barbieri & Green, Washington, D.C.).

Why a Water and Sanitation Decade?

Earthscan

Dried-up riverbed/Lecho de rio seco/Cours d'eau a sec. Turkana. Kenya. Mohamed Amin/Earthscan

Mersa. Ethiopia. ICEF 7512. Bill Campbell/UNICEF

Madras. India. Mark Edwards

Presently, there is a great inadequacy in the quantity and/or quality of drinking water available to large portions of the population throughout the Third World.

Nepal. ICEF 7155. Nik Wheeler/UNICEF

Outskirts of Bogota/Barrio marginal de Bogota/Aux environs de Bogota. Colombia. Felix Tisnes/Earthscan

Earthscan supplies information to the media on environment and development, London, England.

Throughout most of the Third World, fetching water is women's work. If the nearest tap or waterhole is miles away, this can mean heavy, backbreaking labor for several hours every day.

Republic of Korea. Mark Edwards

Rajasthan, India. Sanjay Acharya/Earthscan

Haiti. Mark Edwards

Mexico. Mark Edwards

Haiti. Mark Edwards.

Calcutta, India. 78/001/24. Dutt/UNICEF

Rivers and pools used for drinking can be polluted by industry, agriculture, washing or bathing. Urban water pipes and pumps are often contaminated by sewage, especially when the pressure drops.

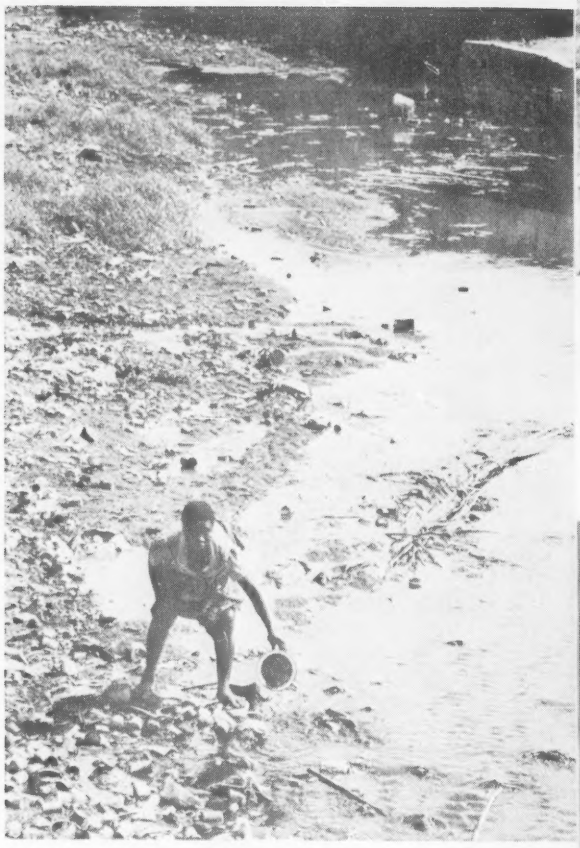
River Nile/Rio Nilo/Le Nil. Egypt. Mark Edwards

Rice paddy water/Aqua de los arrozales/Eau des rizieres. Java, Indonesia. ICEF 7453. Watson/UNICEF

Rajasthan, India. Sanjay Acharya/Earthscan

La Salada, Botota, Colombia. German Castro/Earthscan

Dirty or insufficient water kills. Diarrhea alone probably kills 25 million Third Worlders every year. But clean water, itself, cannot bring health in a dirty, unhealthy environment.



Lagos, Nigeria. Mark Edwards

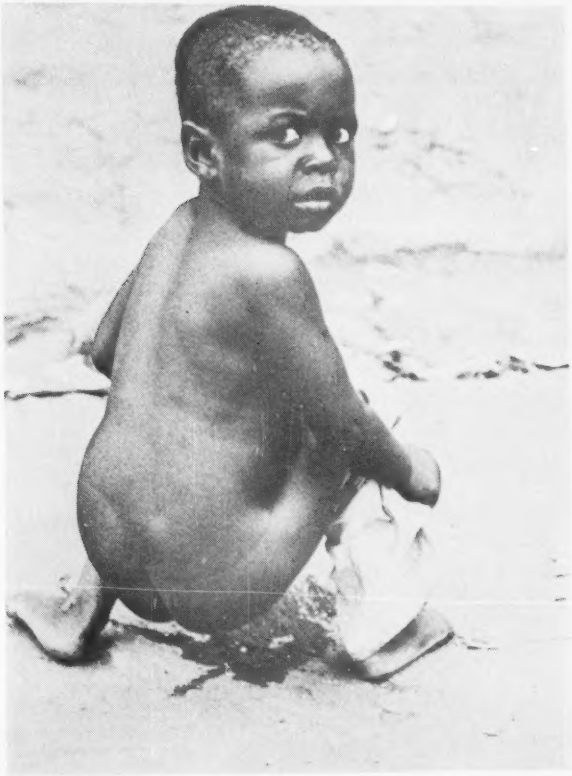
Nepal. Mark Edwards

Lagos, Nigeria. Mark Edwards

Republic of Korea. Mark Edwards

Like dirty water, inadequate sanitation causes disease. In too many developing countries, people still have to wash in drains contaminated with sewage. Safe latrines are essential for basic health.

Open sewer. Alcantarilla a cielo abierto Egout a ciel ouvert. Calcutta, India. Mark Edwards



Lagos, Nigeria. Mark Edwards

New tap/Nuevo surtidor/Nouveau robinet. Malawi. ICEF 7480. Seitz/UNICEF

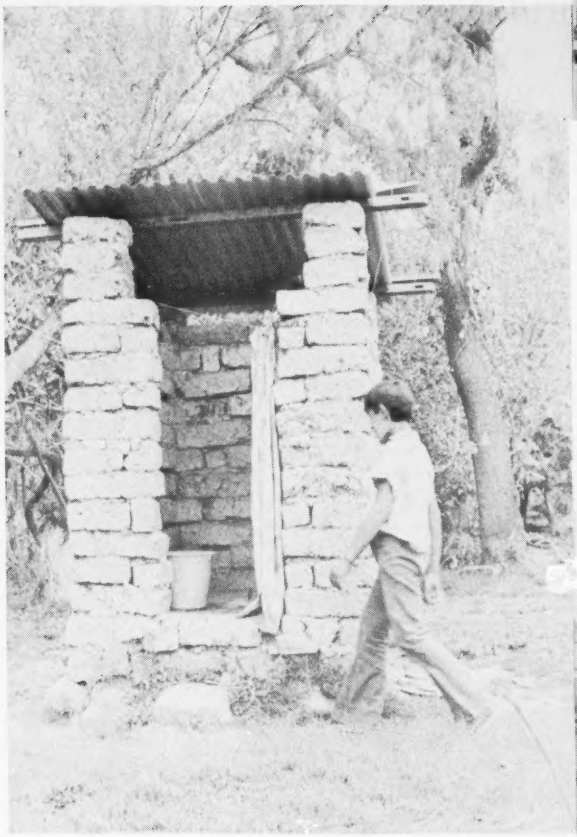
Sarawak, Malaysia. WHO 17117. A J Abeede/WHO

Madras, India. Mark Edwards

Improved water supplies have a marked positive effect upon the health of a population when combined with health, education and community involvement in the improvement activities.

Mexico. Mark Edwards

Urinals/Urinarios/Urinoirs. Calcutta, India. Mark Edwards



Bucket latrine/Letrina de cubo/Seau d'aisance. Calcutta, India. Mark Edwards

Improved sanitation facilities can reduce levels of morbidity and mortality caused by excreta-related disease. However, like improved supplies of water, sanitation must be considered just a part of an overall community improvement scheme if the maximum effects are to be felt.

New latrines and tap/Letrinas y surtidor nuevos/Nouveau robinet, nouvelles latrines. New Delhi, India. Sanjay Acharya/Earthscan

[Photos and some captions from photosheets published by Earthscan, Copyright © Earthscan, London, 1980.]

Supplying Water: Maintenance Problems and Community Participation

Anil Agarwal

[Experience with projects to improve water supplies in both rural and urban areas throughout the Third World has revealed some problems that can and should be avoided in designing such schemes. The use of inappropriate technology, high cost schemes that make it harder to reach larger numbers of people, and a failure to seek or generate community support and participation in projects are some of the main problems. The following article illustrates some failures and successes in dealing with such problems.]

Water for Bangladesh: A Success Story

UNICEF is supporting a major effort to improve water facilities in Bangladesh. Nearly 50,000 tubewells are being installed every year, each serving about 180 people, using a simple technique suited to the country's subsoil. This program should enable Bangladesh to provide safe drinking water for all its 90 million people by 1985.

The average number of inhabitants per tubewell in Bangladesh had already dropped from 385 in 1971 to 162 in 1980, and there is now a much better and more equal distribution of tubewells among the various districts of Bangladesh. There is a proposal to bring down the average ratio to 120 persons per tubewell in 1985, 75 in 1990 and 70 by 2000. Bangladesh now has about 540,000 rural tubewells, and 70% of the rural population now has "reasonable access" to water within 150-200 meters, claims M. A. Hussain, chief engineer of the Department of Public Health Engineering. By 1985, the

Mr. Agarwal is Director of the Center for Science and Environment and a Fellow at the International Institute for Environment and Development in New Delhi, India.

Department hopes to have 718,000 tubewells offering "reasonable access" to everyone. Initially, there were serious maintenance problems, but through simplification of the technology and efforts to involve the beneficiary communities, these have been largely solved.

Bangladesh has sand and silt down to great depths and a water table 5-6 meters (16-20 feet) below the surface almost everywhere. To reach the source of water, a cheap, simple and effective well-sinking technique is now being used which was developed in Calcutta in the 1940s. A 4-5 man team can construct a 30 meter (100 feet) deep tubewell in one 8-10 hour day, including the assembly of the hand pump. No drilling equipment is needed except galvanized iron pipes, a simple bamboo scaffold, and a chain wrench to tighten threaded joints. The iron pipe is simply screwed down into the ground. All the but top length is then replaced with polyvinyl chloride (PVC) tubing. The total cost of the pump and its installation is about US$100. UNICEF pays the cost of the pump and the PVC tubing, the government pays half the labor cost, and the community benefitting from the pump raises the rest--about $26 (400 takas). Where the daily wage rate of farm laborers is only 5 takas (33 US cents), even this investment means a big stake in the pump. UNICEF and Bangladeshi officials believe this initial contribution makes a great deal of difference to maintenance.

For each new pump, a beneficiary from the community is appointed as caretaker. He is provided with simple tools and spare parts for minor repairs, and he can call upon the services of one of the 100,000 government-trained "village mechanics" for major repairs. In this way, UNICEF hopes to reduce the percentage of pumps out of order at any moment from the current 20-25% to less than 10% in 1985.

An additional benefit of the water program is that jobs have been created in several foundries which are kept busy producing the 50,000 hand pumps needed each year. The four inch (10 centimeter) hand pump, specially designed for Bangladesh by UNICEF and manufactured locally from imported pig iron, is assembled in front of the pump caretaker to help him understand it better, as he will be responsible for supervising the maintenance.

Lessons from the Past

Capital investment in drinking water and sanitation facilities in the Third World was estimated at $6-7 billion in 1979. Most of it was spent on water supply programs. These projects have yielded a wealth of experience, but many of the lessons of the past have not yet been reflected in new schemes. Success stories like that of Bangladesh are rare. The often-depressing experiences will have to be taken carefully into account when planning for the U.N. World Water and Sanitation Decade (see page 66). Some of these are the following:

1. Water supply technology is often transferred without any serious consideration of its appropriateness to local conditions. This has led to serious maintenance problems.

2. Inappropriate technology--chiefly involving piped water or waterborne sewerage--often leads to high costs which rural villagers cannot afford, and which governments cannot afford to repeat very often. It is essential to reduce costs if entire populations are to be served.

3. Projects are often undertaken without any reference to what the community feels it needs. Little community participation is attempted, either in execution or maintenance.

4. Cumulative lack of maintenance may create needs as large as those of an unserved population. In many Third World cities, the main water pipes were laid down in colonial times--up

Peru. WHO 16739. Paul Almasy/WHO

Figure 1

to 50 years ago--and have not been renewed since. Today they are overloaded, rusted and leaky--but the capital required for repairs, replacement and extensions is not available.

Hand Pumps: The Problem of Maintenance

Making sure that Third World rural water supply systems continue to work is just as important as constructing new ones. Unfortunately, both governments and aid agencies sometimes seem to forget this.

- A recent study by the Ross Institute of Tropical Hygiene in London estimates that about 30% of Third World rural water systems are currently out of order.
- A 1976 World Bank report stated that in some developing countries water supplies were failing at a more rapid rate than they were being constructed.
- At present, of nearly 450,000 hand-pump tubewells in Southeast Asia, 20-70% are broken.
- "Spot studies showed that nearly 70% of the pumps were not functioning at a given time" - a 1976 evaluation of the UNICEF/WHO-assisted rural water supplies program in India.
- "Approximately 75% of the hand pumps installed by the government program in the investigated wells were not in operation" - a 1976 investigation in Thailand.
- "Bangladesh has a better record for hand pump maintenance than many other countries." But at approximately 400,000 government-owned wells, 100,000 hand pumps are out of operation at any one time - a 1978 report prepared for the WHO International Reference Center on Community Water Supply (IRC) in The Hague.

Arnold Pacey of Oxfam, a British voluntary development agency, suggests that there are three approaches to the problem of hand pump technology and maintenance. In the first approach, the water planner tries to achieve total village self-reliance in the manufacture and maintenance of pumps. Ideally, a pump would be designed so that a village craftsman could make it himself, using simple tools and local materials. Clearly, he could then repair it whenever it went wrong. This approach should work well where the water table is high and pumps are less heavily used, and where a strong tradition of village craftsmanship already exists. Such conditions occur across wide areas

of India, China and Southeast Asia. There is a wealth of traditional water supply technologies in the Third World, but these are generally neglected by engineers and planners, who tend to prefer "modern" technology, so this self-reliance approach is still rarely tried. A British technical adviser has tried to design a pump suitable for villagers to build in rural Ethiopia. The Family Farms project in southern Zambia has a workshop which also manufactures pumps for local use.

The second approach tries to achieve partial self-reliance. Hand pumps can be made in a specialized workshop in developing countries, but the local villagers will be able to maintain and repair them. There are several pumps of this type: the Craelius pump made in Kenya; the Wasp, Kirti and Kaveri pumps made in India; and "New No. 6" designed with the help of UNICEF and made in Bangladesh; and the Dempster model 23F made in the U.S.

In the third approach, the water planner asks for a Western-made pump which is as far as possible maintenance-free, eliminating village-level responsibility completely. This is what colonial administrations used to do, and is sometimes called the "black box" approach. Several decades ago, says Pacey, certain pumps were designed in Britain for use in the colonies, particularly for areas where normal maintenance could not be guaranteed. These were heavily built machines in which a handle attached to a large flywheel had to be turned in order to work the pump. Bearings and other mechanical parts were totally enclosed and protected from dirt and other interference. Such pumps worked successfully for long periods without maintenance, and many are still in use. Only a few of them are now being installed, because of their high cost. A more modern pump which can also operate for long periods without much maintenance is the hand-driven Monolift pump. Both the Monolift and flywheel pumps cost 6-10 times as much as simpler pumps which can do the same job but which do need maintenance.

Approach two, argues Pacey, is closest to the Oxfam philosophy. Its objective is "development," while the objective of approach three--still that of many governments--is "welfare." "Oxfam," he says, "has come to see water supply projects, along with others involving house-building, sanitation and other community-based activities, as being potential catalysts for social development." It is tempting, he wrote in 1976, to criticize UNICEF's pump policy in India as "purely concerned with supplying water on a relief or welfare basis with no component of social development." But he admits that Oxfam has also supported projects close to the welfare approach, with little or no community participation. And UNICEF has, in Bangladesh for example, supported the integration of water supply with community development.

Pacey's views on hand pump maintenance are not entirely accepted by UNICEF, which now strongly supports community participation, as its involvement with the Tamil Nadu pump doctor scheme indicates (see below).

Moreover, UNICEF, unlike Oxfam, must work through governments, most of which still see water as the business of only one ministry, usually public works, and having nothing to do with other ministries handling health, education, or rural development.

Community participation in Latin America. Figure 2
(Pan American Health Organization - Roger Hamilton)

Community Participation

Community participation is a buzz-word today. It is a rare international aid official who does not state that without community participation, drinking water and sanitation programs will fail. What does community participation mean? How can it be achieved? Few people seem to know the answers. But the relevance of community participation can be illustrated from experience.

A report from a typical small village in northeast Thailand illustrates some of the problems. An unique water filtration system was installed which was "a gem of appropriate technology," wrote Simon Watt, a British water engineer, in *New Scientist*. The system was constructed almost entirely from locally available materials. The filters were simple enough for the villagers to maintain without skilled supervision. They were cheap and could be easily copied by neighboring villages.

There were two filtering stages. The first used chopped coconut husks, to remove mud and other solids. The second was burnt rice husks, to remove color, taste and odor, and leave the filtered water clear. The coconut fibers and rice husks had to be changed every two to four months. This filter, developed by Richard Frankel of the Bangkok-based Asian Institute of Technology, did not reach the standards set by WHO. But it was a great improvement on no treatment at all, and offered one way of helping to reduce water-related diseases in rural villages.

The filter system was introduced in 1973, and accepted with enthusiasm. Three years later, it had been abandoned, as had a similar project in a neighboring village. What went wrong? The village headman had volunteered to act as the plant operator. The plant had been ceremonially opened with dignitaries and officials from many kilometers away. The water supply had cost each family about 8 baht (40 US cents) per month, mainly for fuel and repairs to the motor pump. In the first 18 months, however, the motor pump which raised the water up to the filter broke down seven times, and eventually it had to be replaced. When field assistants finally stopped visiting the village, the broken pump remained unrepaired. By July 1977, the motor pump had been removed, the water tanks were empty, and the villagers were back to their old water source: a polluted surface stream in which buffaloes and other animals bathed.

The headman frequently went away from the village for long periods, but because of the prestige which the scheme brought him, he was reluctant to delegate his responsibility. The lack of any local organization to maintain the filtration system, organize payment and collection of water rates, and teach the villagers the full benefits of a wholesome water supply, had rendered the project a miserable failure--despite the virtues of the project technology.

How should community participation be organized for a village water supply project? Arnold Pacey believes it should start long before any drilling or digging. He suggests that villagers should:

1. Formulate a request for help in installing their new water supply;

2. Discuss what sort of supply they need, and where they would like the well or other water points located;

3. Discuss their own contributions, which as well as cash should usually include some physical contribution such as clearing the site before the drilling rig comes;

4. Decide which members of the village should take up any special responsibilities: who should collect the cash, who should organize the work gangs, and who should be in charge of the pump when it is installed.

"If these four steps can be carried through under village leadership," says Pacey, "the drilling rigs and their crews are immediately placed in a less dominant position. They now wait for the villagers to request the well, and then cooperate with them in siting it and in construction... If a project is begun in this way and followed through in the same spirit with full participation by the villagers, many of the problems encountered in well/pump schemes will not crop up at all."

India: The Barefoot Hand-Pump Doctor

> "Providing pure drinking water to thirsty villages is not something engineers can achieve alone. The challenge is to make the people learn that the trouble-free operation of a pump is not so much the government's responsibility as their own. Tirunelveli is a small but sure sign that--given the right approach--the challenge can be met." So claims the staff of UNICEF's south central Asian regional office based in New Delhi.

Tirunelveli, a district in Tamil Nadu state near the southern tip of India, suffered a severe drought in 1975. A crash program was launched to provide drinking water to 11 badly hit districts. The sturdy Sholapur-type pump was used. But in the absence of maintenance support the breakdown rate was about 80%.

In 1976, the Tamil Nadu state government and UNICEF launched a scheme to train "barefoot hand pump doctors," chosen by the villagers. First, rural development officials visit each village and explain the importance of clean water and the role of villagers in maintaining the supply. A village meeting is then held where the village hand pump

doctor is chosen. Often he is the local blacksmith or handyman: someone known to have some familiarity with machines.

The training of a group of hand pump doctors lasts two days, during which they are taught the anatomy of the pump, the diagnosis of common pump ailments, and the simplest rules for coping with drainage problems. The trainees take turns at a microscope, to look at the

Training "handpump doctors"/Entrenando a los "médicos de bombas"/Cours d'instruction pour les "médecins des pompes". 76/042/54. Ken Forman/UNICEF

Figure 3

otherwise invisible germs in clear water and get an idea of the relationship between water and disease. Each pump doctor learns about the importance of drainage, and how to make a soak-pit. He learns about malaria, and how mosquitoes breed in puddles of water. He is taught the importance of using clean containers for storing water, so that the clean water from the pump remains so. Equipped with this knowledge and kit of tools, he returns to his village to become the voluntary (unpaid) caretaker of the pump. In the Tirunelveli experiment, government-paid "gram sevaks" (village-level workers) were also trained so that there would be a standby caretaker for every pump as well.

The duties of the hand pump doctor involve more prevention than cure. It is his task to wean the villagers away from using water from unprotected sources. He must teach them to understand the importance of water storage, and not to dirty the surroundings of the pump. The basic message during the training is formulated as a challenge to the villagers: "Drink clean water for a year and see the difference in your health."

On the pump itself, the main job of the hand pump doctor is preventive maintenance. He does a weekly check-up on the pump, and examines all the external nuts and bolts and working parts. If something is loose, shaky, or crooked, he knows enough to repair the pump. But if something

else is wrong, he uses a prestamped reporting card to summon expert help.

The village hand pump doctor stands at the bottom of a three-tier maintenance system. The uppermost tier is at the District level: a mobile repair team (a junior engineer, mechanic and helper) equipped with a vehicle and a driver. The second-tier is at the Block level, the basic unit of rural administration in India, covering some tens of villages: an inspector-mechanic, whose responsibility is to visit and inspect all the 100 or so hand pumps in his charge. The village-level caretaker is the pivot for not only this rural water supply pyramid, but also for rural health. Since the very first month of the initial training course, the inspector-mechanics of Tirunelveli's 31 development blocks have had a steady inflow of reporting cards.

The Tamil Nadu Water Supply and Drainage Board was so impressed by the results of the experiment that within a few months it issued orders for the three-tier system to be introduced all over the state. It is now gradually being introduced to other states of India as well.

75 Sudan. ICEF 8478. Arila Vollan/UNICEF

Figure 4

Community Participation in Malawi

Malawi is one of the very few countries which is almost certain to meet the "Clean Water for All" target for its rural population by 1990--probably even before that date. To achieve this target, Malawi has only to step up its current water supply program by 13% a year. This achievement would be remarkable considering that Malawi is one of the poorest developing countries in the world. Ninety percent of its 5.2 million population live in rural areas, working largely on subsistence agriculture. Although those who live near Lake Malawi have easy access to water, most of the others have to walk long distances. The key to success has been community participation.

The first approach to water supply in Malawi was to get government and private agencies to dig deep boreholes (120-150 feet; 37-46 meters) equipped with hand pumps. By the end of 1977, about 4,000 such boreholes were spread across the country, and were being adequately maintained by 20 special teams. The cost was enormous. Each borehole served about 130 people and cost about $4,000, about $30 per capita, plus about $70 a year to maintain it.

About eight years ago, a government study suggested how to serve about 75% of the rural population at a fraction of this cost--providing the villagers were prepared to work for their water supply. In other areas, because of geological conditions, boreholes still remained the only solution. A large proportion of the villages use gravity water supplies. Water comes from perennial streams, above the level of cultivation to avoid contamination, and is piped into settling tanks and then directly down to the villages. The major cost is in digging miles of trenches for the pipes. Funds for materials, transport, surveyors and skilled workers to build the settling tanks, are provided by the government. Unskilled labor is provided by the villagers. Construction costs (excluding unskilled labor) per person served averaged only $4 per capita for schemes completed between 1969 and 1977, but have since risen to $6 because of inflation. By 1977, about 1,800 taps were in operation, and 750 miles of pipes had been laid by the villagers.

The Ministry of Community Development and Social Welfare (MCDSW) does not undertake a project unless invited by the District Development Committee (DDC), which consists of members of parliament, traditional authorities and local leaders of the ruling Malawi Congress Party. Once the DDC makes a request, the MCDSW draws up the designs, and the village leaders establish a committee to organize construction, which is shared among the villages using the scheme.

Some villages have dug 20 miles of trench. Work usually starts in February and March after the rains. Women, men and children all join in, bringing their own digging tools. The pipe is produced in Malawi from imported polyvinyl chloride powder (PVC) and is laid by the villagers. The site for each village tap is chosen by the villagers, who also construct a concrete apron around it and a concrete drain into a soakway. At the inauguration ceremony, villagers are told how to operate the tap and the costs they will have to bear if it is broken. The gravity schemes are maintained by village volunteers, after a two-week government training course.

About a million Malawians live in low-lying areas with high water tables. Shallow wells, up to 30 feet (9 meters) deep, are easily dug, but their mud walls crumble, animals use them, and their water becomes contaminated. Initially, the MCDSW tried to protect these wells by making a brick or concrete wall and a raised lip for the well. Labor

was provided by the villagers and material costs borne by the government. But the villagers did not see any great advantage in these protected wells. Children often could not haul up the heavy bucket. Water could still be contaminated by dirty buckets. Progress was slow.

The MCDSW then developed a simple pump that can be made from local materials. It costs only $25-30, compared to the $700-1,000 required for the pumps used on deep wells. This pump is bolted to a concrete lid which encloses the entire well, and it can be operated by children. In 1978, the government undertook to build about 5,000 protected shallow wells, each serving about 100 people.

As with gravity schemes, self-help is playing a major role. The MCDSW provides cement for construction, a concrete slab and all the parts for assembling the pump. The local village committees provide transport by ox-cart for these materials, and all bricks, sand and labor required to construct the well. The materials cost to the government is less than $100 per well: less than $1 per person served. The Malawi government estimates that 30-50% of the rural population will ultimately be served by gravity systems, 25-35% by shallow wells and 25-35% by boreholes.

"The motivation of villagers to carry out self-help schemes," says Julian Bharier, a World Bank expert, "is closely linked to their recognition of the health benefits to be obtained." Most Malawians are illiterate, yet adequate sanitation is important to most people, as the large number of pit latrines in rural villages in Malawi indicates. Since the 1973-74 cholera epidemic, when villages with access to safe water were scarcely affected, the number of cases of diseases associated with water supply and sanitation has declined each year, illustrating the power of example in that nation. It is hoped that this case might also encourage safe water supply development elsewhere in the world.

[Extracted from Water and Sanitation for All? Earthscan Press Briefing Document No. 22, 1980, pp. 37-47. Copyright© Earthscan, London, England.]

Sanitation and Well Building

S. B. Watt and W. E. Wood

[Clean drinking and washing water can greatly reduce or eliminate a number of widespread diseases. However, new and improved wells must be kept free of contamination if they are to accomplish this purpose. The following article describes ways in which improved water facilities can be protected from contamination.]

Many of the diseases that cause illness and death to mankind are 'water related' in one way or another. They can be listed under various heads, e.g.:

(a) Water-borne diseases--those that may be carried in water and infect consumers. Cholera, dysentery, typhoid and hepatitis are of this class.

(b) Water-based diseases, where the organism causing the sickness spends part of its life cycle in an aquatic host, for example guinea worms or schistosomes.

(c) Water-shortage diseases, or diseases of dirt --those whose incidence could be reduced if ample water were available for washing and hygiene. Scabies, tropical ulcers, trachoma and infantile diarrhea are examples.

(d) Water-associated diseases, spread by insects that breed in water. Malaria, river blindness and sleeping sickness come under this heading. The mosquito, simulium fly or other causative agent is described as a 'water-related insect vector.'

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The first two of these classes can be drastically reduced by providing water that is free from infection. The third class will become less prevalent if sufficient water is available for personal washing and domestic hygiene, so the construction of wells giving ample supplies of safe water will serve to protect the public from all three. The fourth class of diseases will not be directly affected by well construction, but there may be an indirect effect if villagers no longer have to frequent swamps or other infested spots to collect their water. For example, schistosomiasis can be reduced if women and children do not have to enter infested water to collect their domestic supplies or to wash clothes. However, these remarks apply only to a hygienic well--one that has been designed and constructed in such a way as to protect the water it contains from contamination, and that is used and maintained in a hygienic manner. If these conditions are not fulfilled, the well, instead of being a factor of community health improvement, may actually become a means of spreading those very diseases that it was designed to prevent.

Hygiene education is essential if the full benefits of any water supply improvement scheme are to be realized. Well-users must understand the risks of contaminated water and the need for safe waste disposal in order to appreciate the necessity for protecting the supply.

Most water-related diseases are spread by wastes from an infected or ill person transmitted to the water supply in some way. Man is the main reservoir of most of the diseases that make him sick, and all water supply improvement schemes should be supplemented by sanitary measures that cut the cycle of disease by the efficient disposal of human wastes. These should include the protection of the water supply from contamination and, where appropriate, the treatment of the water to destroy any disease-causing bacteria, viruses or parasites before it is used.

Prevention of Contamination of a Well

There are three routes by which the water in a well may become contaminated: through the wellhead (see Fig. 1), through the lining, or through the water entering the intake.

An open well without a wellhead is always potentially dangerous. The ground around it becomes worn and slopes towards the shaft, allowing rain and spillage to wash into the well. In addition, in areas where guinea worm is endemic, the eggs of this parasite are carried into the water below to transmit the disease to a subsequent user. Hookworm and other infections can flourish in the soil immediately around the shaft, to be picked up by the bare feet of the villagers. If people are allowed to enter the well, to use unsanitary buckets to raise their water, to defecate or to wash themselves or their clothes

in the vicinity, or if animals are permitted to approach the open well mouth, a whole new range of disease-spreading contamination may pollute the well.

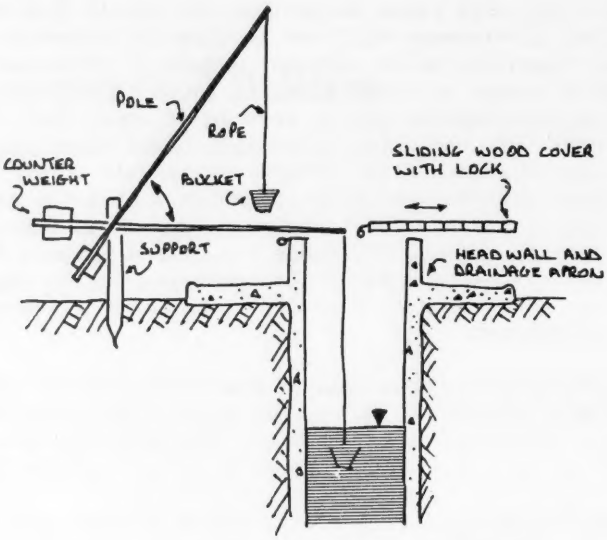


Figure 1. Domestic water supply. Brick-lined shallow hand dug well with headwell and drainage apron. Water is lifted out by bucket 'Shaduf' device made from bamboo. The bucket remains suspended above ground between periods of use. A sliding wooden cover which is locked by the well owner prevents rubbish from being thrown into the well. Thailand.

A properly designed wellhead can exclude most of these hazards. Two features are essential: a curb or headwall rising sufficiently high above the ground surface to prevent anything from washing or blowing into the well mouth, and narrow enough to discourage users from standing on it; and an impervious apron 2m wide, sloping away from the shaft in all directions. Around the outer edge of the apron there should be a raised rim to prevent spillage or waste water from running over the edge of the apron into the ground around the well. This rim collects the water for release into a pipe or impervious channel which carries it to a "soakaway pit" a safe distance away. (See Figure 2.)

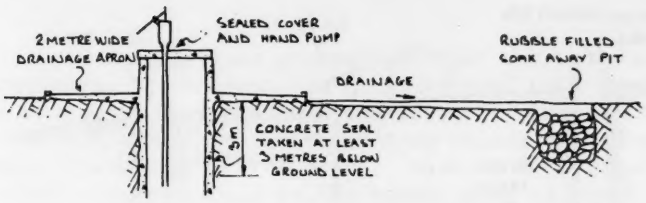


Figure 2. Prevention of wellhead pollution.

For complete safety a raised sealed cover is needed, but such a cover is most practical where a pump is fitted into it, as in Fig. 2. Where the well is to be left open for ropes and buckets to be used to draw the water, precautions must be taken to minimize the hazards of contamination. A moveable cover may be provided to protect the shaft from wind-blown dust, insects and the like when the well is not in use.

Pollution may enter through the shaft lining if this is not water-tight. When a well is sunk through material such as sandstone, hard laterite or other rock, the walls of the shaft may be sufficiently strong to stand without support, and in such cases lining is often omitted. However, the top 3 meters at least should always be made waterproof by lining to prevent seepage from the surface soil layers, which are the most likely to carry dangerous contaminants. When a well is lined with material other than concrete, e.g. brickwork, masonry or similar substitute, particular care must be given to ensuring the water tightness of the top 3 meters and its junction with the wellhead.

The water in the aquifer may become polluted before it reaches the intake. A source of pollution, such as a pit privy or animal pen, will produce contaminated water that will soak downwards into the soil. Usually the polluted drainage will become filtered and purified within a short distance as it travels downward, but if the water table is too close to the surface, purification may be incomplete before the water enters the intake. A well should therefore be located as far away from potential sources of pollution as possible, certainly no nearer than 50m, and at a higher level of the water table. (See Fig. 3 and 4.) Obviously the more densely populated the area the more difficult this will be to achieve. It may be possible to arrange the privies in the immediate vicintiy to be cleared before well construction starts, but the saturated ground around them may remain hazardous for a long time after their use has been stopped.

One further potential hazard may render the water in a well unpleasant or impossible to drink--a concentration of salts dissolved from the soil by the groundwater in its passage to or within the aquifer. Some of these (e.g. chlorides, sulphates) make the water bitter or un-

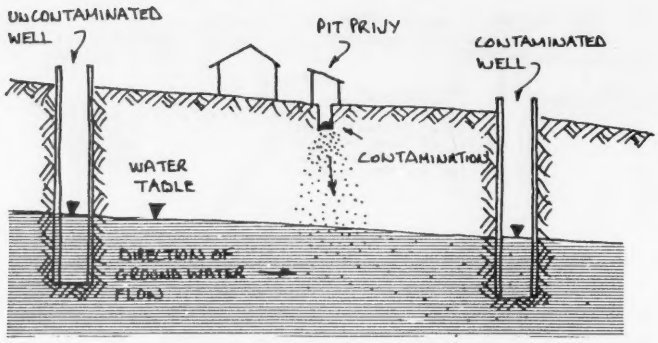


Figure 3. Contaminated wastes from pit privy soaking down to the aquifer and into the well.

palatable, some may be dangerous in excessive concentrations (e.g. heavy metals, nitrates), some constitute a nuisance only (e.g. iron salts that stain clothes washed in the water). All are difficult and expensive to remove. If there is any doubt a sample of the water should be sent for chemical analysis before a well is opened for public use. Salt concentrations in the ground usually occur over a fairly wide area, and evidence of their presence in nearby wells should always lead to suspicion that any new well may produce water that is not safely potable.

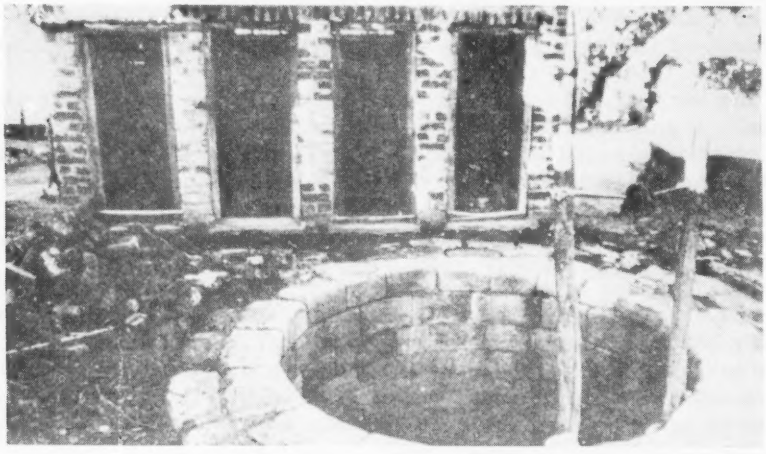


Figure 4. Wellhead Contamination--New latrines were built alongside a well, which will now have to be abandoned. Even if the well is filled in, the aquifer is still liable to be contaminated. India.

There are certain other precautions that can be taken by the village authorities. If animals are to be watered this should be done (preferably from properly constructed troughs) some way from the wells, and the wellhead should be fenced to keep animal droppings and the beasts themselves clear of the apron. Washing facilities for people and for their clothes should be far enough away to avoid the drainage seeping back into the ground around the wellhead.

Disinfection and Maintenance

Upon completion a new well should be properly disinfected before use, since it may have been contaminated by the well diggers themselves. Disinfection can be accomplished in numerous ways. One effective means is to lower a sealed but porous pot containing chloride of lime into the well. Such a pot can give protection for two or three weeks without the concentration of chlorine in the water ever rising to an unpalatable level. Health risks can be reduced by simple hygienic precautions during construction; above all, defecation within the immediate vicinity of the well must be forbidden.

Arrangements must be made for a well's future maintenance and hygienic use before it is used. Good maintenance depends on the designation of a person responsible for keeping the structure in good order. Hygienic use can only be achieved if well-users know how careless use of the well can contaminate the water and how this unsafe water can affect their health and that of their neighbors. Community support must be won; experience has shown that persuasion can achieve results that regulations cannot. Community participation in construction and maintenance is evidence of strong community support and concern.

Where the well is an open one, periodic cleaning should be arranged. In some parts of the world this is made into a special occasion at the time of the lowest water level, with the villagers cooperating in drawing the water in the well to the lowest level possible, while one or two men are lowered into the shaft to remove any accumulation of rubbish, sediment or vegetable growth. After such cleaning the well should again be disinfected before being put back into use.

Hygienic usage is made easier if the wellhead is designed with this in mind. If a pump is fitted this is easier to achieve, though an important point to watch is that the pump be self-priming or that there be a tank for priming water--contamination can start from dirty water used to prime a hand pump. Where the well is an open one a potential source of pollution is the use of ropes and buckets. This can be minimized if communal ones are provided, so fixed to the wellhead that they cannot be removed, thrown on to the ground, or stored in an unsanitary manner. In places where it is customary and unavoid-

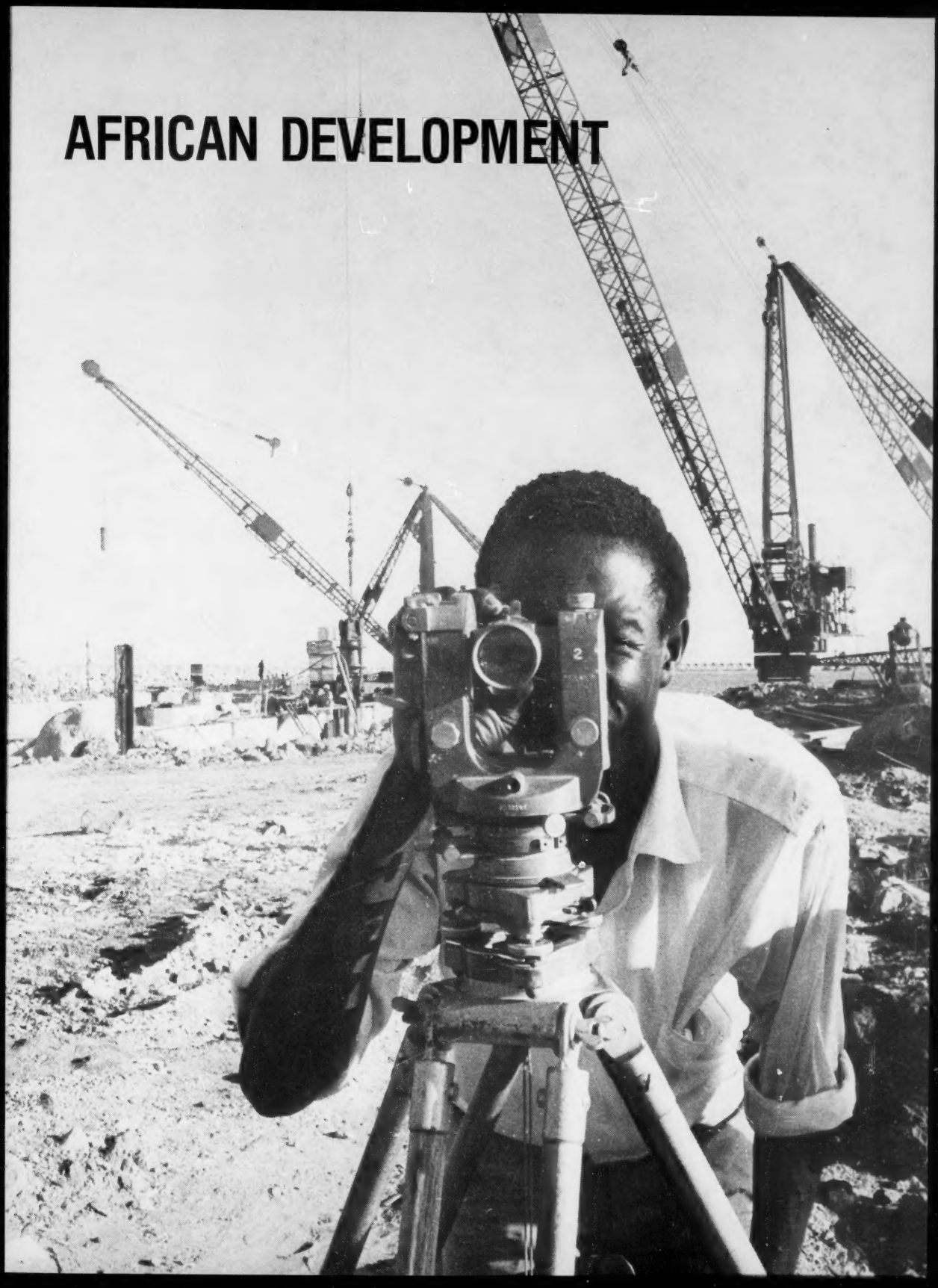
able for villagers to have their own ropes and buckets, these items should be hung up clear of rats and domestic animals when out of use, and not deposited on bare ground near the wellhead before and after they are used for drawing water. Further, it should be made the responsibility of a particular individual to see that the surroundings of the well are kept clean and in good repair. The apron should be swept; cracks in the concrete should be repaired; the area should be drained and the pump kept in good working order.

At the same time it is a good thing for health officials to explain the importance of protecting domestic water after it has been taken from the well. Disease can be spread within a family through water stored in open pots in the home, especially if these are not protected from domestic animals, rodents or insects. Precautions against the breeding of mosquito larvae in domestic water pots are especially necessary in areas where malaria or yellow fever are prevalent. Filariasis may be spread where spillage or waste water is allowed to collect into pools, and the resulting infection is not confined to the household where the nuisance occurs.

A final point concerns special precautions to be taken whenever there is a particular health hazard such as an epidemic of cholera or typhoid in the neighborhood. In cases like this it is wise to add a mild but continuous dose of disinfectant to the water in the well.

[Extracted from Chapter 2, Hand Dug Wells and Their Construction. Copyright© 1979, Intermediate Technology Publications Ltd., London.]

AFRICAN DEVELOPMENT



GHANAIAN SURVEYOR AT WORK ON A CONSTRUCTION SITE NEAR ACCRA, GHANA (Photo: UNESCO, Marc Riboud).

Perspectives and Problems of Development in Sub-Saharan Africa

Shankar N. Acharya

[This paper analyses the history and initial conditions for development facing post-colonial African nations, and outlines development strategies followed by two different groups of countries. Policy priorities for the future include greater research, extension and infrastructure support for smallholder agriculture, a more realistic urban formal sector wage structure to reduce rural-urban migration and foster more internationally competitive manufacturing, and more emphasis on savings generation.]

The Historical Legacy

The pre-colonial setting. The research findings of the Leakey family and others indicate that man's origins may be found in East Africa. But after the species had spread to other continents, Sub-Saharan Africa was increasingly isolated from land masses to the north and east by the spread of deserts across Sahara and Arabia. These deserts, and the non-navigability of major rivers, reduced the contacts of Africans with other cultures and deprived them of the mingling of peoples which can stimulate civilization. The 15th century A.D. witnessed the first major contacts between Sub-Saharan African societies and the mercantilist European nations, which were destined to leave their colonial imprint on Africa.

The overwhelming majority of Africans at that time were engaged in subsistence farming. As most soils of tropical Africa tended to be light, low in plant nutrients, easily leached by heavy rains and scorched by the sun, the farmers adjusted to these natural deficiencies by means of shifting cultivation, usually based on slash-and-burn techniques. In most parts of the savannah and bush

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country shifting cultivation was facilitated by the virtually limitless supply of land. The system discouraged permanent individual rights in land. When communities moved, individual farmers could stake out their new fields with family labor as the chief defining constraint. Communities were typically delineated by kinship. A political concomitant of shifting cultivation was that chiefship tended to be over people rather than land; European-style feudalism based on land-scarcity was unknown. Other types of agriculture were practiced by nomadic herdsmen, like the Somali and Masai.

Commerce was nourished by, and in turn nurtured, the West African medieval empires of the Niger bend, such as Ashanti, Dahomey, Mali, Benin, which flourished in the 14th-19th centuries. Some of these empires were founded on the long-distance trade which took gold, ivory and slaves from West Africa across the Sahara to the Maghreb and Europe in return for salt, cloth and beads. Profits from the trade not only sustained some of the states, but also nurtured craftsmen (jewellers, weavers, iron-workers, potters, masons, carpenters), who met the local needs of the better-off-merchants and nobility. Sometimes, as in Benin, the rulers derived power and profit from their control over long-distance exchange. At other times state power relied less on the cash nexus and more on protection offered their subjects, favors and a variety of religious, judicial and political services. Conversely, commerce did not always require strong state systems. From the viewpoint of long-run economic development, the traditional West African long-distance trade suffered from one grievous handicap: it relied much too heavily on assets like gold, ivory and slaves that were found or captured, and very little on production.

In comparison with contemporary Europe and Asia, one aspect of Sub-Saharan African societies is sharply silhouetted: their technological backwardness. Some key examples: one Bronze Age invention prevalent throughout Eurasia, the plow, had not yet reached Sub-Saharan Africa (except Ethiopia). This meant animal power could not be harnessed to farming. Another weakness was in adapting the wheel to its numerous potential uses, including harnessing wind and water power and as an integral element in various irrigation devices.

The advent of European mercantilist interests on the west coast of Africa in the 15th century had profound consequences. First, the existing overland trade links were gradually supplanted, in relative significance, by the European-controlled maritime commerce linking the West African coast to Europe, as well as points on the West African coast to each other. One important consequence of European mercantilism was the massive boost it gave to the slave trade. Slavery had existed for many centuries and in many forms, but pre-colonial Africa had never developed large-scale plantation economies. The European conquest of the New World led to the institution, in the Americas and West Indies, of large tropical-crop plantations (sugar, tobacco, cotton, coffee). Millions of captives

were shipped across the Atlantic in the course of the four centuries during which the trade flourished. Aside from the severe human cost to those directly afflicted, this process drew off from the continent human beings at their most productive ages. Worse still, it encouraged tribe to fight tribe and encouraged conflicts within tribes. The slave trade plunged vast stretches of Africa into anarchy. The final consequence of Europe's 15th-century coming to Africa as that it led, step by step, to the extension of European military and political domination over the continent, culminating in the 1880s when the continent was comprehensively carved up among the rival European powers.

The impact of colonialism (1890-1960). The early years of colonial rule were characterized by a mixture of physical repression and the founding of the infrastructure of modern economic states. In their territorial expansion in quest of commercial opportunities and minerals the European chartered companies and concessionaires, in collaboration with their imperial mother-nations, fought bloody battles of subjugation. On the other hand, colonial rule put an end to slavery and slave-raiding. And the railways and roads did get built; they inevitably opened up vast tracts of African hinterland and gave an enormous fillip not only to the European-controlled mining, but also to African commercial agriculture. Given the earlier paucity of wheeled transport, and the susceptibility of pack animals to fly-borne diseases, the impact of railways and lorries on African economic development was enormous (some adverse consequences were the more rapid spread of communicable diseases). New crops, like cocoa, sisal and cotton, were introduced and propagated. A start was made with public health facilities to control the effects of diseases affecting man and livestock. Schools were built, with the missionaries taking the lead. Above all, once the colonizing conflicts had been fought to their conclusion, the system provided the minimum of public security necessary for economic development.

In sketching some of the lasting elements of the colonial imprint, it is useful to distinguish two types of experience: the 'white-settler colonies' of East and Central Africa; and the peasant economies of West Africa.

There are three major characteristics of the economic evolution of the 'white-settler' colonies, as exemplified by Kenya and Southern Rhodesia (Zimbabwe). First, the development of African commercial agriculture was retarded, at least until the early 1950s when the policy was reversed. The colonial administration used policies of land alienation, discriminatory orientation of government research, credit and extension services, controls on prices and markets, and outright bans on African farming of certain crops, to develop and maintain the profitability of European farms. The "African reserves" served as pools of wage labor to the European farms.

Second, modern industry began much earlier in the settler colonies than in the peasant economies of West Africa. One reason seems to have been the pro-industrialization influence of a resident European population which possessed the necessary technical, managerial and entrepreneurial skills, the requisite contacts with home-based firms, and the political leverage to influence the colonial administration to grant support and protection to nascent industrial activities. Where local industry (albeit controlled either by Europeans or Asians) had an early start, the disruption of trade caused by World War II gave a major import-substituting boost to industrialization.

Third, the settler colonies were generally characterized by a tradition of state intervention in the economy. From the earliest years of British colonial rule in East and Central Africa state monopolies over export crops were set up. Restrictions were imposed on who might sell what to whom. Industrial licensing, currency restrictions, trade controls and tariffs proliferated. World War II greatly increased the variety and intensity of the colonial administration's intervention in these economies.

The outstanding differentiating characteristic of the West African peasant economies was the linch-pin role of African farmers throughout the colonial period. Except for a few plantations in the Ivory Coast, Liberia and Nigeria, the market-oriented production of both export crops and foodstuffs was in the hands of African peasants. This had three major economic consequences. First, by the mid-20th century the average West African peasant from the Gold Coast (Ghana), the Ivory Coast, Nigeria or Senegal enjoyed a much higher standard of living than his counterpart in East and Central Africa (except for some regions of Uganda). Second, this long history of commercial farming provided the experience necessary for large numbers of Africans gradually to move into wholesale and retail trade, transport and various artisan activities. Third, amongst the African farming population there evolved a much higher degree of economic differentiation than in East and Central Africa.

While the colonial period was marked by a prolonged agricultural boom, industrialization lagged in West Africa. One reason given by economic historians is the highly monopolistic character of the export-import trade in these economies. As early as 1930, four companies accounted for 60% of the export-import trade. The monopolistic position was strengthened and preserved through to the mid-1950s and was successfully deployed to discourage any local manufacturer from taking over any significant share of the market. Nor was there any white-settler population of consequence to exert the pro-industrialization supply-side pressures which existed in East and Central Africa. After the mid-1950s, however, there was a massive spurt in industrialization, when the surge in imports broke down the old oligopolistic barriers around the import trade and induced a series of market-protecting local industrial investments by the previously dominant trading firms.

World War II witnessed an enormous increase in the responsibilities and roles of government in the Allied nations of the West. This trend found reflection in much more actively development-oriented policies of the colonial administrations. This was the period when "colonial planning" effectively took shape as a result of a mixture of efforts by the local authorities to express their needs in a more explicit form, and by the metropolitan powers to integrate capital outlays for overseas territories in their own national plans. This was particularly true for the French colonies and somewhat less so for the British. Furthermore, financial aid in the former was always exclusively in the form of grants and quasi-grants, whereas loans, mostly on soft terms, were the rule in the latter. Investment was mainly oriented toward infrastructure, especially highways and ports. At the same time the welfare of Africans became a more explicit concern of colonial policies. Expenditure on African-oriented agricultural support services also increased. Besides a few large, ill-conceived, and widely publicized attempts at large-scale mechanization (the Kongwa scheme in former Tanganyika, the Casamance groundnut scheme in Senegal), there were serious though unequally successful efforts at organizing African farmers at village level for productive and distributive purposes ('co-operatives,' 'sociétes de prévoyance,' 'paysannats indigènes' etc.).

The post-war era was also one of intensified state intervention in trade and money, especially in the Franc zone area. This resulted in trade arrangements especially advantageous to exports from the metropole and beneficial to the colonies in terms of stable prices and assured markets for their primary products. The system had lasting effects among former French colonies, in the form of regional and subregional common markets and common currency arrangements that have been instrumental to this day in facilitating movement of goods and people alike, and minimizing balance-of-payments problems among members that have adhered to the Franc area system.

Initial conditions at independence. Most of the Sub-Saharan African countries attained political independence in the late 1950s and 1960s. The majority of these countries were blessed with relatively favorable arable-land-to-population ratios at independence. However, the quality of land was typically poor because of topography and climate. In about three-quarters of Sub-Saharan Africa rainfall is scanty. Where rainfall is bountiful, year-to-year fluctuations are great, and the intraseason pattern frequently uneven and unpredictable; both aspects hinder rainfed agriculture. Across most of Sub-Saharan Africa soils are derived from old acid parent rock which is poor in calcium and plant nutrients. And if green cover is removed, the high heat of the tropical sun and/or heavy spasmodic rainfall easily threaten the thin layer of humus on which plant life depends. When that happens the soils readily turn into infertile laterite. There are, of course, significant exceptions to this endowment of poor soils, in the shape of the rich volcanic soils in some East African highlands and the alluvial

clays of the coastal plains. The tropical climate of Sub-Saharan Africa can constrain human endeavor. The high heat and humidity engender lassitude, and these climates are very hospitable hosts to a formidable range of parasitic and infectious diseases, which exact a toll in morbidity and death; the absence of winter, as a natural killer of vector-borne diseases, is a significant factor. The most well-known of these scourges are bilharzia, malaria, river blindness, sleeping sickness, parasitic worms, yellow fever, cholera and leprosy.

Minerals were an important magnet drawing colonialists to Africa. But their recent and foreseeable role in economic development is limited to a handful of countries where the known mineral resources are concentrated: Zambia, Zaire, Botswana, Gabon, Sierra Leone and Zimbabwe.

For most Sub-Saharan African countries the colonial heritage of trained indigenous manpower was abysmally small. The rapid development of schooling facilities after World War II had ensured that the primary-school enrollment ratios by 1960 (25-60 percent in most cases) were not dramatically lower than in other developing areas. But the proportions in secondary and higher-level education were very much lower--at most 2 or 3 percent in secondary and very few at university level. As for Africans with experience in administrative, managerial, financial and technical pursuits, such cadres were extremely thin.

Apart from formally trained manpower, the indigenous populations of the newly independent African states were endowed with very limited entrepreneurial experience. In East and Central Africa, commerce, finance and industry had been almost exclusively the preserve of Europeans, Asians and Arabs. The entrepreneurial heritage in some of the West African economies was more promising. The long exposure of Africans to commercial farming and then commerce had begun to spawn significant numbers of small African enterprises engaged in the craft trades of tailoring, woodworking, goldsmithing and motor repair, as well as more mainstream manufacturing activities like baking, printing, bottling, sawmilling, soapmaking and even manufacture of electric motors. The heritage was, of course, unevenly distributed with Nigeria, Ghana and Senegal leading the field.

At independence, almost all the Sub-Saharan African nations were small open economies with foreign trade accounting for 20% or more of national product. Typically the export trade was characterized by heavy dependence on a few primary commodities. Except in the mineral-producing countries, these primary commodities were agricultural items like coffee, cocoa, tea, palm-oil, cotton, oilseeds and sisal. There were few inter-industry links, since the overwhelming bulk of the processing of the exportable agricultural surplus had been conducted in the imperial, importing nations. Barring the mineral producers, agriculture was the dominant sector, accounting for 40-60% of national

product, with half or more of value-added being generated in subsistence activities which provided means of livelihood to the majority of the population. The modern infrastructure of railways, roads, banks, power and water utilities and commercial networks serviced the links between the productive cash economy (commercial farms, plantations and mines) and the former metropolitan nations which purchased its produce in return for manufactured producer and consumer goods. Urban communities were small, but usually growing rapidly.

At the end of their day the colonial administrations loomed large in the economic life of these nations, not only in national accounting terms, but also in the scope of activities they controlled through legislation, administrative fiat and extra-government public agencies like marketing boards. The middle and upper levels of wage and salary scales of the colonial public sector were designed to facilitate recruitment from the colonial nations, and were thus set according to prevailing pay-scales in those countries; they bore no sensible relationship to the average standard of living in the African nations. Thus, it was commonplace to see ratios of 30 or 50 to 1 between top public service salaries and average (or legal minimum) wages of unskilled labor, which was in marked contrast to the ratios of 4 or 5 to 1 to be found in Great Britain or the United States. The inappropriate structure of public incomes was compounded by policies with regard to perquisites such as housing and car subsidies. This sort of "inappropriateness" also spilled over into excessively high design standards for public services such as water, lighting, health and housing.

Perhaps the strongest institutional bequest of colonialism was the concept and practices of a nation state which transcended ethnic and kinship ties. This is not to belittle the role of the African nationalist movements which helped to bring about independence, but rather to recognize that the crystallization of such nationalist sentiments and political parties were spurred in many cases by the fact of colonial rule. It is also to recognize that the geographic boundaries of the sub-Saharan African states were usually the outcome of colonial history, and frequently not congruent with indigenous cultural and linguistic demarcations. Nationhood, in the form of the apparatus and practices of a modern state, came to Africa very fast and created formidable new challenges to expand traditional loyalties, which tended to be limited to kinship groups and tribes, to embrace the nation. Stanislav Andreski has argued (e.g. Development Digest, July 1969, p. 74) that the hurried onset of statehood and very rapid urbanization has severely diluted the traditional (largely tribal and in rural settings) moral restraints without there being time enough to nurture new supratribal loyalties and obligations to the institutions of the modern state, thus leading to a situation of 'moral disorientation,' conducive to unrestrained and highly individualistic pursuit of wealth and power through any means at hand. This is probably too extreme a view. It may be more appropriate to recognize that since independence there has been a race to instill and

nurture the notions of supratribal loyalties and ethics before customary webs of obligation won out (or crumbled too early), a race which may have been temporarily lost or won in some countries, but which has almost nowhere been run to a finish.

Colonial rule not only left behind the large new apparatuses of modern states, but also a heritage of public intervention to solve perceived problems of the populace. To some extent the latter-day paternalism of colonial administrations bred, amongst the affected populace, a syndrome of dependency toward the state in respect of free (or subsidized) services such as schools, hospitals, water, sewerage, roads, lighting and housing. While these public benefits had been mainly limited to a few urban communities where most of the colonial rulers lived, with independence the expectation of such benefits spread far wider to the much more numerous rural populations. This 'consumptionist' approach to public services was a colonial heritage with major post-colonial consequences.

Development Strategies--Two Leading Types

In attempting to review the post-independence development policies and experience of the Sub-Saharan countries, an analyst is confronted by the enormous variety of policy choices and diversity of results. To do justice to this richness of experience would require a separate study of each of 40 odd countries. However, the high degree of abstraction necessary in a paper as short and broad-ranging as this one forces a search for the commonalities in policies and experience.

It is useful to distinguish between two broad kinds of development strategy pursued by the post-colonial Sub-Saharan African nations. The first was characterized by some or all of the following elements:

(i) a high level of state ownership and investment in modern sector industry, agriculture, transport and commerce, combined with a penchant for public control over resource allocation in all key sectors;
(ii) rapid Africanization of middle- and high-level jobs in the economy;
(iii) a deliberate effort to 'force' the pace of industrialization and a willingness to accept the resultant skewing of the structure of incentives against agriculture; and
(iv) a skeptical attitude towards foreign trade and investment, which typically spawned inward-looking production priorities rather than efforts to expand foreign exports.

Using the first feature for a short-hand label, this strategy may be termed 'étatist.' The second strategy boasts some opposite characteristics:

(i) relatively greater reliance on markets, especially international market forces, for guiding investment and output allocation, with state enterprises limited *mainly* to the traditional public utilities and various types of infrastructure which support the directly productive sectors;
(ii) slower Africanization of high- and middle-level manpower;
(iii) a greater willingness to let the pace and character of industrialization be governed by market forces; and
(iv) a tendency to view external trade and investment as a source of gains.

Following the earlier convention, the short-hand label for this strategy is 'market-oriented.' This label merits some qualification. Virtually all Sub-Saharan African governments were highly interventionist, though the étatist ones were considerably more so, especially regarding the degree of state ownership of productive enterprises. Perhaps the crucial distinguishing characteristic of the market-oriented countries was the degree to which they permitted international market forces to govern their pattern of economic specialization; étatist countries were far more prone to try and swim against world market tides.

We will focus on a limited number of countries which followed the étatist strategy--Guinea, Ghana, Sudan, and Tanzania. Countries which have followed a more market-oriented strategy include the Ivory Coast, Kenya and Malawi. In terms of the number of countries and the populations they contain, the étatist strategy has been the more influential in post-colonial Sub-Saharan Africa. The countries chosen for comparison represent clear cases of strategy choice, and have good economic data; none had oil or minerals for export which would bias the comparison.

Development experience. A base period (1960) snapshot of the seven countries reveals broad similarities in the structure of output. Agriculture accounted for two-fifths or more of total value-added, with, as one would expect, the poorest countries like Malawi and Tanzania displaying the higher shares. Manufacturing accounted for less than 10% of GDP in all countries. Its share was usually comparable to that of the transport-and-communications sector and invariably less than that of trade. There were greater differences in the disposition of national output. Leaving aside the exceptional case of Malawi (with negative saving in 1960), gross national savings ranged from a low of 5.4% of market-price GNP in Guinea to a high of 16.2% in Ghana. The share of gross domestic investment in GNP varied from 8.7% in Sudan to a high of 24.7% in Ghana, where the 'big-push' development policies of the Nkrumah government were well underway. Imports of goods and non-factor services ranged between a quarter and a third of GNP, with exports averaging a little lower, except for low 12% values for both in the Sudan.

Growth rates of real GDP, agriculture and manufacturing between the early 1960s and 1975 are summarized in Table 1. First and foremost, it is clear that the market-oriented countries had a significantly higher rate of growth of GDP, averaging 6.9% a year, than the étatist nations which averaged only 3.8% a year. Indeed, Malawi and the Ivory Coast are the only two nations in all sub-Saharan Africa which achieved growth rates of 7% or higher over an extended period and without the benefit of mineral exploitation. In Tanzania, Ivory Coast and Kenya growth was slower after 1970 than before; part of the explanation must lie with the vicissitudes of the international economy and the droughts which affected agricultural production in many countries in 1973-1975. A growth rate in agriculture greater than 3% seems to be a necessary, if not a sufficient, condition for relatively rapid GDP growth. There is no apparent correlation between the *achieved* pace of industrialization and the extent to which the objective was considered central to development policy. Thus manufacturing in Malawi and Ivory Coast, neither of which gave primary emphasis to industrialization, sustained annual growth rates of 13 and 10%, respectively, while in Ghana which slanted development policies in favor of industrialization the long-term industrial growth rate was only 2.6% per year. While the share of manufacturing in GDP stagnated around 10% in Ghana between 1960 and 1974, it grew from 7.1% (1960) to 14.2% (1975) in the Ivory Coast and from 5.8% (1960) to 14.5% (1975) in Malawi.

Table 1. Growth in real value added
(per cent per year, at factor cost)

	Period†	GDP	Agriculture	Manufacturing
Étatist countries*				
Ghana	1965–1974	2.8	3.9	2.6
	1965–1970	2.3	3.9	4.4
	1970–1974	3.3	3.8	0.2
Guinea	1960–1975	3.8	2.8	11.3
	1960–1970	3.6	2.7	14.7
	1970–1975	4.4	3.0	5.9
Tanzania	1964–1975	4.8	2.9	7.9
	1964–1970	5.4	3.4	10.5
	1970–1975	4.2	2.3	4.7
Market-oriented countries				
Ivory Coast	1960–1975	7.3	3.7	10.0
	1960–1970	8.1	4.5	11.3
	1970–1975	5.5	2.1	7.6
Kenya	1964–1975	5.8	3.2	8.4
	1964–1970	6.6	4.7	7.2
	1970–1975	4.9	1.6	9.9
Malawi	1964–1975	7.5	4.8	13.0
	1964–1970	6.3	3.7	15.1
	1970–1975	9.0	6.2	10.5

Source: World Bank data.
* Data for Sudan were under revision.
† For each country the longest possible period with consistent data has been used and then divided into two subperiods around 1970.

Developing agriculture. Both sets of countries inherited economies in which agriculture was by far the largest sector, providing livelihood to 80% or more of the population, the vast majority of whom were smallholders. Étatist nations were prone to emphasize structuralist approaches to agricultural development over gradualist ones. The former approach was typified by the concentration of scarce public capital and trained manpower on a few large-scale schemes, and/or emphasis on state-sponsored institutional reorganizations of the rural sector. Thus in Ghana during the 1960s newly established and mechanized state farms received the bulk of agricultural development funds, while the extension service for smallholders languished. This led to the deterioration of extension services, the politicization of credit allocations and the antagonization of the peasantry. In Tanzania, between 1961 and 1967, public development capital was lavished on a handful of village settlement schemes which suffered from premature mechanization, excessive investment in social services and an unwarranted degree of what Dumont has termed 'spoon feeding. In 1967, the economic differentiation among the peasantry, resulting in part from the uneven advantage taken of these services, sparked a series of egalitarian Government institutional initiatives, including the 'ujamaa' campaigns, the 1972 decentralization of Government and the 1974-1976 crash villagization program. While these initiatives were aimed at creating a framework conducive to long-term, broad-based rural development, the prolonged flux in the peasant's institutional environment exacted a significant short-term toll in foregone rural production and incomes. In Sudan, investment, research and qualified manpower resources were concentrated throughout the period on a few massive, state-run irrigation schemes (such as the Managil extension of the Gezira, the Khasm-el-Girba scheme, and the recent Rahad project) and some programs in support of private, mechanized farms. The 10 million people earning a livelihood from traditional rainfed smallholder cultivation were residual in the agricultural development effort.

In contrast, the market-oriented countries made support of private peasant production the main plank of agricultural development policy. Though these countries tended to steer clear of direct state production in agriculture, there was no lack of public investment in infrastructure, research, marketing, extension and credit facilities. Thus it is noteworthy that agriculture was receiving 36% of total public investment in the Ivory Coast in the period 1966-1970, compared to 30% in Tanzania in 1974-1975. The market-oriented countries sustained and expanded successful programs of adaptive research in individual cash crops. In the Ivory Coast specialized, long-established research institutes for coffee, cocoa, oilcrops and cotton worked closely with the 'development societies' for these crops. In Kenya, the newly-independent Government built on the inherited research programs in coffee, wheat and pyrethrum. The Kenya Tea Development Authority pioneered a system of 'tea roads,' smallholder extension, and organization of collection and process functions which permitted smallholders to become efficient producers of tea--usually regarded as a plantation crop par excellence. The successful adaptation

of hybrid maize for smallholder cultivation in high-potential areas of Kenya was a rare success story of adaptive research in foodcrops in Sub-Saharan Africa. The governments in market-oriented countries usually provided qualitative encouragement to progressive farmers, instead of viewing them as unwelcome harbingers of an entrenched kulak class. For example, in Malawi, the 'Achikumbe' program provides various kinds of benefits and recognition to smallholders who consistently achieve certain high standards of husbandry and market orientation.

The external sector. Given the initial openness of the Sub-Saharan African economies and the foreseeable demands for increased import flows, a successful, long-term export policy was a prerequisite for a sustained development effort. That was easier said than done. The initial export structure of these countries was heavily dependent on a few agricultural commodities. The choice facing most was whether to deepen the existing specialization further on the basis of comparative advantage or attempt to nudge the evolution of export competitiveness away from agricultural products. A strong attraction of the latter choice was the very sharp declines in external terms of trade that these countries had experienced between the mid-1950s and 1960-1962, and which was an important explanation for the ambivalence towards primary exports shown by many newly independent countries. The market-oriented countries cast their lot on the side of continued specialization in agricultural exports, with the partial exception of Kenya which also pursued manufacturing export markets in the partner countries of the East African Common Market. Not coincidentally, these were also the countries which sustained the most favorable environments for private peasant agriculture. The étatist nations on the other hand were, on balance, less favorably disposed towards both private peasant agriculture and further specialization in agricultural exports.

The information in Table 2 supports some surprisingly clear-cut judgments on the relative efficacy of these choices. First, the fears of a long-term decline in the terms of trade were not misplaced. Comparing 1954-1956 to 1973-1975, all countries but Sudan experienced substantial declines in their commodity terms of trade. But the real issue was whether, given the correctness of such a prediction, these African countries had a viable alternative export policy to one of continued specialization in agricultural exports. If the past two decades of experience are any guide, the answer seems to be negative. Comparing 1954-1956 to 1973-1975, the export volumes of the Ivory Coast, Kenya and Malawi increased five-fold, four-fold and three-fold, respectively, while they failed to double for Ghana, increased by about 50% in Tanzania and stagnated in Sudan. What is even more telling is the record on the purchasing power of exports. These indices stagnated for Ghana and Sudan, and rose by a third in Tanzania. In contrast, the index tripled for the Ivory Coast and more than doubled for Kenya and Malawi. The market-oriented countries were clearly able to generate volume increases which far outweighed adverse price trends, through a policy of continued spe-

cialization in agricultural exports combined with increasing diversification among agricultural commodities.

Table 2. Indices of export volume, terms of trade, and purchasing power of exports: 1970 = 100

	1954–1956	1960–1962	1966–1968	1973–1975
Etatist countries*				
Ghana				
Export volume	66	85	71	123
Terms of trade	148	90	94	75
Purchasing power	98	75	67	92
Sudan				
Export volume	65	84	80	60
Terms of trade	119	89	97	132
Purchasing power	77	75	78	77
Tanzania				
Export volume	52	78	103	76
Terms of trade	123	95	102	111
Purchasing power	64	73	102	84
Market-oriented countries				
Ivory Coast				
Export volume	29	56	83	157
Terms of trade	139	77	95	79
Purchasing power	40	43	80	125
Kenya				
Export volume	25	63	89	101
Terms of trade	154	96	97	87
Purchasing power	38	60	86	88
Malawi				
Export volume	48	51	102	148
Terms of trade	111	100	89	77
Purchasing power	53	51	90	113

Source: *UNCTAD Handbook of International Trade and Development Statistics*, 1976.
* Data are not available for Guinea.

Entrepreneurship and industrialization. The lack of a strong class of African industrialists tended to confront policy-makers with a choice between continuing with the colonial heritage of an industrial sector owned and controlled by private non-African groups (including both foreign transnational investors and local ethnic minorities), or 'Africanizing' modern industry through nationalizations and public investment in industrial plant. Most countries veered towards the latter path. Ghana and Guinea led the way immediately following their independence in 1957 and 1958, Tanzania followed suit after the 1967 Arusha Declaration, and Sudan in 1969. The three market-oriented

countries, the Ivory Coast, Kenya and Malawi, continued to rely predominantly on foreign private investment and management for industrial development.

Thus far the development of successful African industrial entrepreneurship, whether in private or parastatal modes, has been limited. At the time of independence the greatest promise for private African entrepreneurship appeared to be in some of the coastal West African economies like Ghana, Nigeria and Senegal. But very soon after independence, these countries activated strong import-substitution policies, including detailed administration of import and industrial licenses, which tended to favor the larger established foreign subsidiaries and new government industries, and be biased against emerging, small-scale indigenous manufacturers. These policies, together with the existing handicaps of the environment, inhibited the evolution of private African entrepreneurs. In the lower-income East African countries it was probably too early to expect a significant transition of Africans from cash farming to industry. In all these countries the availability of relatively well paid and secure government jobs dampened proclivities for industrial ventures. In the étatist countries like Ghana, Guinea, Sudan and Tanzania, the emergence of private industrial African entrepreneurs was further inhibited by the anti-private-sector stances of government policies.

Almost by definition, the scale of state entrepreneurship in the industrial sector of the étatist countries has increased greatly. Given the relative infancy of the industrial sector, it is probably too early to form a definite evaluation of African state entrepreneurship. However, in most countries policies of import restrictions, tariffs, preferential access to domestic and imported raw materials and intermediate imports, confinement schedules and subsidized credit and equity terms have created a highly protective framework which discourages striving for efficiency. Many of these features of the macro-policy-frame are also to be found in some of the market-oriented countries. But in the case of parastatal firms the macro-policy problems are compounded by the weakness of firm-level incentives for workers and managers, their inexperience, the multiplicity and diffusiveness of objectives, and the transference of bureaucratic procedures from civil-service backgrounds. Comparisons of product per unit of labor or capital in parastatal versus private firms show higher productivity in private firms by some 100 percent in Ghana, and by 20-40 percent in Tanzania (depending on the measure used).

Wage policy and its effects. Both the colonially-bequeathed wage structure and the subsequent course of policies had significant implications for growth and income distribution in the Sub-Saharan African countries. The colonial period bequeathed a widely divergent public pay structure, which was mirrored in the urban private sector. Not only was there an enormous difference between the top European salaried

official or company manager and the unskilled African wage-earner, but the wage of the latter had had to be set high enough to attract rural peasants with a relatively high reservation price into 'permanent' urban wage labor. Around the end of the colonial period these unskilled urban wage rates tended to become codified in minimum wage legislation. After independence there was rapid Africanization of the administrative grades of the civil service, but without any significant change in the pay structure. One major reason for this was that it was politically extremely difficult to reduce the pay of senior African civil servants substantially so long as the old pay scales (or even better ones) were necessary to retain many of the ex-colonial expatriate staff in the more technical government functions. And in the private modern sector, foreign firms continued to pay their predominantly expatriate senior staff the same high salaries as before. Thus, post-independence pressures to reduce the massive disparities between the top and bottom of the urban pay structure could be accommodated more easily by raising the pay scales at the bottom. This is what happened.

There were several significant consequences. First, during the first decade after independence the gap in real earnings between smallholder peasants and urban unskilled workers or clerical staff widened greatly. Consequently the demand for such urban formal-sector jobs expanded much faster than supply, and the positions had to be rationed --usually on the basis of educational qualifications, such as primary-school leaving certificates. This, in turn, generated a massive demand for education, where the emphasis was on the diploma (rather than the content of education) as the passport to formal-sector jobs. There was no comparable reward attached to the more difficult process of acquiring vocational or craft skills. The supply of education increased rapidly, especially in rural areas, partly in response to the vastly increased demand and partly to well-grounded desires to reduce illiteracy and ignorance. Armed with the necessary certificates large numbers of rural youth migrated to urban centers to engage in the lottery for relatively well-paid formal-sector jobs. As the rate of growth of such employment typically lagged behind the combination of natural increases in existing urban labor force and the growth of migration to towns, the result was increasing urban unemployment, the growth of an informal sector, and greater urban poverty, all relatively new phenomena in Sub-Saharan Africa.

Thus the adverse consequences of wage policy included:

(i) widening urban-rural income differentials;
(ii) the emergence of urban unemployment and poverty;
(iii) excessive investment in the wrong type of education;
(iv) price inflation and reduced government savings;
(v) increased protection of the nascent industrial sector;
(vi) increased orientation within industry in favor of capital-intensive activities; and

(vii) a failure to reward craft skills necessary for the evolution of African non-government enterprises.

In varying degree, these policies and consequences may be found in both étatist and market-oriented countries. The presence of a well-developed mineral sector tended, as in Zambia, greatly to accentuate the problems of an inappropriate wage structure. Labor earnings were typically very high in the capital-intensive mineral sector and tended to impart a strong upward bias to the entire formal-sector wage structure.

Policy Priorities for the Future

Given the stage these Sub-Saharan African countries had reached by the 1980s, what are the critical long-term development issues that they must tackle to provide the best hope for self-sustaining development that helps to alleviate poverty? [Note: A major World Bank study will be published, autumn 1981, entitled: "Accelerated Development in Sub-Saharan Africa: An Agenda for Action."]

The demographic setting. Of all the regions of the world, Sub-Saharan Africa displays the highest fertility and mortality rates; and while mortality rates have been declining, there has yet to be any significant change in fertility rates; so the rate of population growth is likely to accelerate before it declines. Although historical data on mortality rates in these countries are scarce and unreliable, it is clear that over the past two or three decades there has been a significant decline, leading to increases in life expectancy at birth of 7-10 years between the early 1950s and early 1970s. Total fertility rates have remained high, in the range of 5.5-7.0, with crude birth-rates clustering around 45-50 per 1,000. Except in the two small island nations of Mauritius and Réunion there has been no significant decline in fertility. Indeed in some countries, fertility appears to have risen in recent years. Rates of population growth range between 2.5 and 3.5% per annum.

The continuing pattern of low life expectancy is attributable to extremely high rates of infant and child mortality, explained by the usual features of high incidence of communicable disease, malnutrition, gastric diseases, poor traditional midwifery and weaning practices. Where fertility is believed to have risen in recent years, it has been attributed to adult health factors such as higher fecundity and reduction of secondary sterility.

With continuing improvements in general health conditions, all those factors which will improve women's ability to conceive and bring pregnancies successfully to term will tend to increase fertility. There is much debate on the effects of urbanization and education on fertility. Parents' recognition that they cannot afford education (especially secondary education) for large numbers of children is probably the best

hope for future fertility decline. Very few governments presently endorse strong family planning programs. Even when governments adopt such programs, as in Kenya, the spread of family planning measured by numbers of acceptors does not appear to be accelerating; and program activities are still mainly confined to the highly educated.

Thus the outlook for the next two decades is for continued (and sometimes even accelerating) rapid population growth. Ultimately, as improvements in child mortality reduce the number of desired births and education offsets strongly held pro-natal feelings, fertility can be expected to decline. In the meantime, economic policy-makers must plan on the basis of high rates of population growth. Two obvious consequences of this growth will be: (i) increases in social service spending budgets, which should strengthen the case for institution of cost-recovery systems; and (ii) acceleration of the shift in agriculture from land-extensive cultivation systems to more scientific ones.

A strategy for agriculture. For most of these countries, in the medium and long run, the key to more rapid growth, swifter alleviation of poverty, containment of unemployment, the reduction of urban-rural income differentials, a more manageable balance of payments and a more robust basis for long-term structural transformation of the economy, lies with increasing production in the rural economy. While industrialization of the right kind can play a strong supportive role, its capacity to generate employment and incomes directly will be quite limited for decades to come. Thus, for example, in Tanzania, where the choice of industrial strategy has been the focus of sustained analysis and debate during the past five years, long-term simulations reveal that whatever their other differences, none of the strategies under consideration offers a scale of manufacturing employment greater than a mere 3% of the projected labor force by 1995. In the 1970s employment in the organized manufacturing sector in higher-income countries like the Ivory Coast and Ghana accounted for only 2% or so of their labor force. For the foreseeable future the task of providing productive employment for the growing labor force of these nations must rest squarely with the agricultural sector.

Within the agricultural sector the long-term objectives of growth, poverty alleviation and structural transformation are likely to be best served by concentrating resources and policies in favor of smallholder agriculture. Smallholder agriculture offers the best opportunities for transforming abundant resources of land and labor into output, while economizing on scarce factors of capital and foreign exchange. This is true both for the present endowment of resources and for likely future technical innovations.

Large-scale, capital-intensive agricultural modes (state farms, private estates) are likely to play only a limited role in the optimal

long-term strategy for agricultural development in Africa. Such capital-intensive agricultural modes (at least, the privately managed ones) are frequently associated with higher land productivity than peasant farming. Less often they also boast greater total factor productivity. Amongst their attractions for policy-makers are the ready accessibility of their production. But there are two principal arguments against emphasis on private estates and state farms even when they pass the test of static economic efficiency. The first reason is based on equity: the benefits from estate production are likely to be distributed much less widely than those from smallholder production of the same output. The second reason follows from this: because the diffusion of their incremental incomes is limited, estate farms are less likely to set in motion the broad-based increases in rural purchasing power that are necessary to bring about a mutually supportive dynamic interaction between agriculture and domestic industry, of the kind which has transformed the economy of the Indian Punjab in the last 15 years.

The force of these cautionary remarks varies among countries. For example, in land-abundant countries like Zambia and Zaire, large farms based on hired labor may be an appropriate mode of production for quite a few years before the demographic pressures on land sharpen the issues of market pre-emption by large farms cutting off the income-earning opportunities for smallholder farming. In countries where land is less abundant, like Kenya and Ethiopia, the arguments based on market pre-emption are already persuasive. As the demographic trends press harder against the availability of land there will be more Kenyas and fewer Zambias in the future of Sub-Saharan Africa. The details of an appropriate smallholder strategy will vary, but some principal elements are likely to be common to all countries.

First, the incentive bias against agriculture present in the policy frames of most countries needs to be substantially diminished. This will require hard decisions on exchange rates, tariff structures, formal-sector wages, retail price controls, and agricultural producer prices. In addition to increasing the purchasing power of rural incomes through such policy reforms, the distribution systems must be developed to convey manufactured consumer goods upcountry to enable purchases from the increased incomes. If these actions are taken, one can confidently predict substantial increases in rural incomes and production. That smallholders will react positively to improved price incentives can be reliably asserted on the basis of the wealth of evidence from all over the globe--including Africa.

Second, throughout the greater part of Sub-Saharan Africa, population growth is gradually inducing a transition from resource-based, land-extensive farming to science-based, land-intensive practices. Virtually all studies of African farm systems carried out in the 1950s and 1960s stressed the labor-constrained nature of agricultural output; but

the doubling of the population in the last quarter of a century is changing all that. Like all transitions the picture is mixed. There are still substantial opportunities for increasing output by expanding the cultivated area, both through shifts into lower quality lands and through opening up good virgin land by extension of the rail and (primarily) road networks. But the pressures for land-intensive cultivation are now being clearly felt in many areas. In Kenya 'high-potential' land is virtually exhausted and in certain pockets landlessness has begun to emerge as a significant social problem. Population pressure is also being felt in the good land areas of the Arusha, Kilimanjaro and West Lake regions of Tanzania, and in northern Ethiopia and the Sahel countries. Benneh has estimated that in recent years in Ghana the average fallow period has been reduced from 6-10 years to 2-3 years in the predominant bush fallow system of cultivation. All of this suggests that in the long term growth in agricultural output will come increasingly from improvements in the intensive use of land, stemming from better husbandry and greater use of fertilizer, pesticides and improved seeds.

Given the enormous heterogeneity of the rainfall patterns and soils and the relatively small stock of research, especially in foodcrops, the transition to a science-based, land-intensive farming strategy will be a long, slow haul. The need for location-specific adaptive research is great, especially in semi-arid zones. Special attention needs to be devoted to rootcrops and coarse grains, which are particularly prominent in African food production and consumption. Adaptive research will need to embrace biological-chemical innovations such as seed-fertilizer combinations, as well as mechanical innovations. There is an urgent need to strengthen the capacity of national and regional research organizations to generate an efficient sequence of technical innovations that are feasible and profitable for small farmers.

High-yield 'technical packages' will need to be combined with improvements in cropping and tillage practices. To ensure that all this complex information is readily available to the farmer will require wider and faster-reacting extension service systems than are presently available in most countries. Providing for a dialogue between African farmers and researchers is difficult at present, but is essential for increasing the impact of research on farm productivity and output.

In present-day Africa irrigated agriculture is expensive and technically demanding. In the short and medium run it makes more sense to focus adaptive research and development programs on the predominant rainfed mode, including the semi-arid areas which are increasingly being brought under cultivation. But in the long run irrigation could have a greater role, and some attention needs to be given to accumulating hydrological data and beginning to acquire the necessary expertise and experience for the design and management of irrigation schemes.

Third, one readily transferable technical innovation, the tractor, should be approached with extreme caution. The experience with tractorization schemes in Sub-Saharan Africa is, on balance, unfavorable. Most tractorization schemes have been characterized by overcapitalization, poor organization, inadequate repair and maintenance facilities, inefficient use of machines, high land-clearing costs and insufficient increases in output; and tractorization is typically labor-displacing. Recent research by the World Bank on the comparative economic profitability of technologies found tractors inferior to oxen cultivation, even when it was assumed that all of a village's land was farmed as one unit; this was even more true for individual peasant holdings.

This does not mean that African farmers should be condemned in perpetuity to the presently prevailing system of manual cultivation based on the hoe. The potential from improved tools and implements is particularly promising for oxen-based farming systems, wherever soils, topography and the tsetse fly permit. Indeed, a fourth element of a smallholder-oriented development strategy would be the institution and encouragement of oxen cultivation, and related propagation of new tools and implements. Control of the tsetse fly is important. Breeding programs need to be developed for stronger, more effective oxen for cultivation. A broad range of implements and tools has to be developed, tested, produced and marketed; and animal power should be harnessed to a wider range of farm tasks than is currently the case. The integration of draft animal power into farming practices will also require changes in social customs and attitudes towards the role of cattle and in the rules governing their access to grazing land. Furthermore, local small-scale manufacture of a widening range of hand-tools and animal-power implements (such as plows, cultivators, seed-fertilizer drills and planters) can stimulate the growth of rural-based manufacturing activities, especially the growth and diffusion of metalworking and other technical skills essential for the evolution of broad-based manufacturing capabilities and non-farm employment opportunities. The burgeoning rural workshops of India, Pakistan, Taiwan and China have proved to be fertile ground for the development of efficient and increasingly sophisticated small-scale manufacturing enterprises.

The fifth component of a smallholder strategy must be to reduce the transport and marketing margins between the peasant and the point of final sale. Principally, this will involve improvements in physical transport infrastructure, especially feeder roads and storage facilities, and measures to increase the operating efficiency of marketing and transport intermediaries. The inefficiency of parastatal marketing and transport agencies is a particularly pressing problem in étatist countries, where their role is much greater.

The role for industry. Though the manufacturing sector now contributes from 10 to 15% of GDP in the Sub-Saharan African countries, its contribution to employment has been no higher than 2-3% of the labor force (the figure may be 3-6% if various informal-sector units are also included). Typically 80% or more of industrial value-added is in import-substituting activities, principally in 'early-stage' lines like food and beverage processing, textiles, garment manufacture, wood products, paper and printing, but with a sprinkling of very capital-intensive projects in cement, fertilizers, metal-processing and petroleum-refining. There is a substantial bias in policy within the industrial sector in favor of import-substituting activities and against production for export. There is widespread economic inefficiency in industrial activities attributable to a variety of causes:

(i) lack of competitive pressures due to heavy protection granted by the policy frame;
(ii) uncertain and chaotic implementation of quantitative import restrictions, confinement schedules and other market-fragmenting devices;
(iii) scarcity of management cadres and middle-level industrial skills;
(iv) inefficiencies and interruptions in supply of key supporting infrastructure such as transport, power and water;
(v) virtual absence of industrial consultancy and technical services;
(vi) policy discrimination against small-scale enterprises, which are frequently the training ground for indigenous entrepreneurs;
(vii) special problems of parastatal enterprises, such as diffuse objectives, excessive and insufficiently coordinated government intervention, and weak incentives for managers and workers.

The nub of this summary is not that Sub-Saharan African countries should not industrialize, but rather that certain kinds of costly errors and 'non-solutions' should be soft-pedalled, while some positive actions are supported.

This should not be read to mean that there is never a sound case for protecting industry. The generalized infant industry arguments (such as skill acquisition, growth of entrepreneurship) may well warrant a moderate degree of special advantage for industry relative to other sectors. Ideally, this should be at a uniform rate (20-30% as a rule of thumb) for all industrial activities and should not discriminate between import-substituting and exporting options. There may be certain exceptional cases which warrant greater inducements for

special reasons. Thus the metal-working sector may be particularly favored for its special possibilities for skill acquisition and the longer-term capability for indigenous technological adaptation.

But in granting such special treatment to industry, three considerations should be kept uppermost. First, it is vitally important to keep some competitive discipline alive in the nascent industries. Second, the notion of infancy as a temporary state should not be forgotten. There needs to be some recognition of the desirability of future reductions in the special advantages initially granted. Finally, the government should not neglect the development of 'structural' supports to industry such as technical and consultancy services, accounting training, and physical infrastructure.

Formal-sector wage policies. The benefits of a lower real wage and slower growth of wage rates in future may be briefly recounted. First, a lower real urban wage will, other things being equal, mean reduced urban-rural income differentials. As a consequence the demand pull for rural-to-urban migrants would be reduced, as would the associated problems of urban unemployment and poverty. Second, a lower real wage should, in a protected, cost-plus pricing system, be associated with lower prices for manufactured goods purchased by rural dwellers. Third, lower unit labor costs in the formal sector should enhance the competitiveness of potential manufactured exports. Fourth, lower labor costs should augment corporate or parastatal surpluses and reduce government recurrent budget expenditures, thus, on balance, increasing domestic savings. In an étatist economy an increase in parastatal surpluses should not be associated with any worsening of the urban household income structure, a possibility which clearly exists in the case of private corporate surpluses which typically yield income to richer segments of the household distribution. Finally, the lower attractiveness of wage employment should increase the relative attraction of non-wage income opportunities, such as small enterprises and craft occupations. Thus, a lower real wage (and/or slower growth) should have unambiguously favorable effects on economic efficiency and growth. The effects on income equity are likely to be favorable, on balance, especially in the étatist countries.

Mobilizing domestic resources. Both étatist and market-oriented countries generally achieved considerable success in raising their revenue-to-GNP ratios between 1960 and 1975, from 10-15% up to 20% or more. However, the concomitant, and frequently faster, growth in recurrent expenditures severely constrained the growth of government savings, as measured by the ratio of recurrent budget surpluses to GNP. Given the recurrent budget claims for past development projects and continued pressure for increased social services, it would be unrealistic to expect much of a savings dividend from the budget.

Indeed, in several countries, unless the expansion of social services is accompanied by the institution of cost recovery measures and much greater local 'self-help' efforts, the government could become a significant net dissaver.

In the next decade or so, the task of generating adequate domestic savings must lie principally with the parastatals (state enterprises) and the private sector. In the étatist countries, parastatals must assume a large share of the savings responsibility. To a great extent the measures to increase parastatal efficiency will help to increase their savings. Basically a parastatal savings strategy must embrace two themes: one for generating higher gross surpluses in the first instance, and another for protecting these surpluses for investment finance instead of having them transferred to entities which use this finance for consumption. In pursuing the latter aim it may be worth experimenting with various kinds of earmarking devices.

The role for private savings is likely to remain larger. This will certainly be the case in market-oriented countries. In both groups of countries, to the extent that policy encourages the income and productivity growth of farms and small-scale businesses which combine saving and investment roles, the inducements for increased effort and investment may be enough to call forth the increases in savings necessary for self-financed investment. However, it can be anticipated that with greater urbanization the proportion of households who are not direct investors will increase. Hence there is likely to be a greater role for financial institutions to mobilize such potential household savings and allocate them efficiently. This, in turn, will require reforms in financial institutions and more active interest rate policies than have been pursued hitherto.

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Food Problems and Prospects in Sub-Saharan Africa

U.S. Department of Agriculture

[Food production in Sub-Saharan Africa has not kept pace with population growth, and with present trends the gaps will widen. The development of higher productivity in farming methods requires better economic incentives to farmers, adaptive research work, and big investments in marketing and transport facilities.]

Sub-Saharan Africa is the only region in the world where per capita food production declined over the past two decades. This decline exacts a high price in both human and economic terms. The human price is inadequate nutrition: in most Sub-Saharan countries the per capita calorie intake falls below minimal nutritional standards. The economic price of inadequate food production is an increasing demand for food imports at a time when grain prices are rising, and many African governments face acute balance of payments and foreign exchange problems.

Projections to 1990

Our study finds that the implications of this pattern are severe. Using a series of equations which project the dynamics underlying production and consumption between 1965 and 1979, we estimated import demand and unmet food needs in 1990 if historical trends continue. If 1975 real per capita income levels and producer price patterns prevailed in 1990, Sub-Saharan Africa would have an import gap of 11.5 million metric tons (cereal equivalent). Even with these imports, there would still be large unmet food needs: bringing

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diets up to minimal calorie consumption levels (about 2300 calories per person per day) would require an additional 12.4 million tons.

Even if we assume that there is positive growth in real per capita income, and that such growth follows 1965-79 patterns (essentially smoothing out the effects of the 1974-79 economic setback), the picture is disturbing. The import gap would rise to 18.5 million tons--some 11.9 million tons of this for West Africa alone. Because income growth is so unequal among regions, diets would reach adequate levels in West Africa, while major unmet food needs would persist in the Sahel, Central and East Africa. Meeting these needs would require an additional 9.1 million metric tons of cereals. If growth were to follow more recent 1974-79 trends, the regional skewing is even more extreme: under these conditions, the 1990 import gap would be 21.1 million tons--with 18.2 accounted for by West Africa, and 10.1 million more tons would be required to eliminate calorie deficits. The conclusion seems clear. If growth follows historical patterns, there will be dramatic increases in the paying demand for imports by 1990, yet very little reduction in the quantity of food required to respond to unmet food needs.

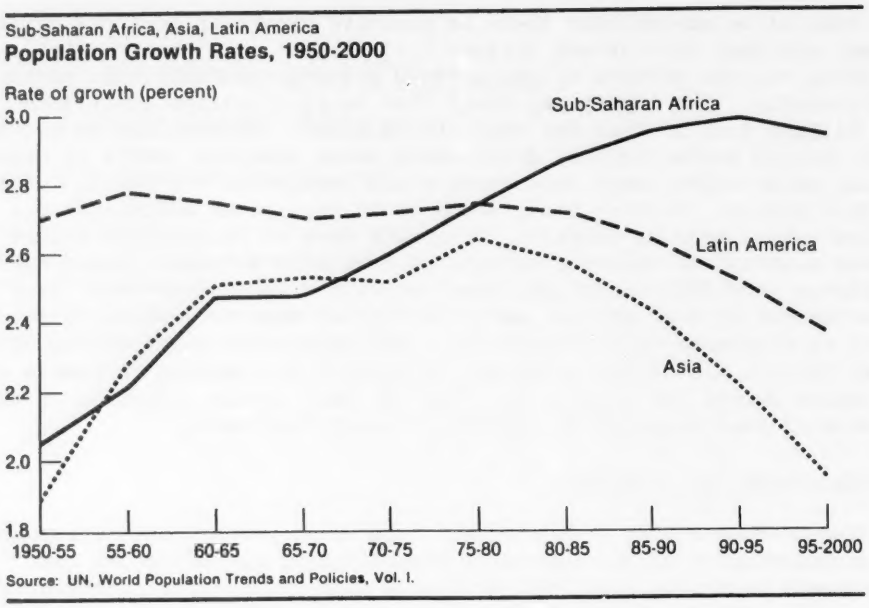
General Causes for Problems

Why is Sub-Saharan Africa's food balance so precarious? The population growth rate of Sub-Saharan Africa is high, but there has been poor growth in productivity and aggregate food production. Therefore, much of the problem appears to be on the supply side. The increasing population plus rapid urbanization are exacerbating major weaknesses in African food production and distribution systems.

Sub-Saharan Africa's population growth rate has increased steadily over the past 20 years--from 2.05 percent in the mid-fifties to 2.74 percent in the late seventies (Figure 1), and it now has the highest rate of population growth of any of the developing regions. Furthermore, population growth rates are projected to remain high over the next decade, according to United Nations projections. They are not expected to level off until about 1990, when they will average about 3 percent per year. Most of the population impact on food demand in the 1980s is built into the structure of the present population.

A special demand problem is posed by urbanization, since the interaction between urbanization and income growth creates a structure of demand which is difficult to supply from local resources. Sub-Saharan Africa is presently the least urbanized region in the world, with less than a quarter of its people living in cities. The urbanization rate, however, is high, and urban population growth rates of 5 percent or more per year are common. With an annual growth rate of 5 percent, an urban population will double within 14 years.

Figure 1



Urbanization puts a premium on convenience foods such as bread, rice, and processed foods which are often difficult to supply from local agricultural resources. Few Sub-Saharan countries can produce wheat in any significant quantities. Rice production is possible but is frequently high in cost--both in relation to world market prices and in comparison with the cost of producing other staples. Commercial processing of local foodstuffs is not well developed. Meeting the rapidly expanding urban demand for food from local resources will require better procurement and marketing policies, improved infrastructure, greater attention to the processing and storing of local staples, and attempts to change urban food habits.

At the same time total food production in Sub-Saharan Africa has grown very slowly--about 1.8 percent per year in the 1960s and 1970s. This is below the aggregate growth rate for Asia or Latin America. Some countries actually recorded declines in aggregate production between 1961-5 and 1979. Productivity has also been low (Figure 2); African cereal yields are less than half those in Asia. Yields for pulses, as well as for roots and tubers, are about two-thirds of the Asian yields, and are not generally increasing. Thus, growth in food production has depended heavily on expanded area; increases in cultivated area have frequently offset declining yields (Table 1). In the Sahel, both area and yield have declined significantly during the last decade.

Figure 2

Yields for Cereals

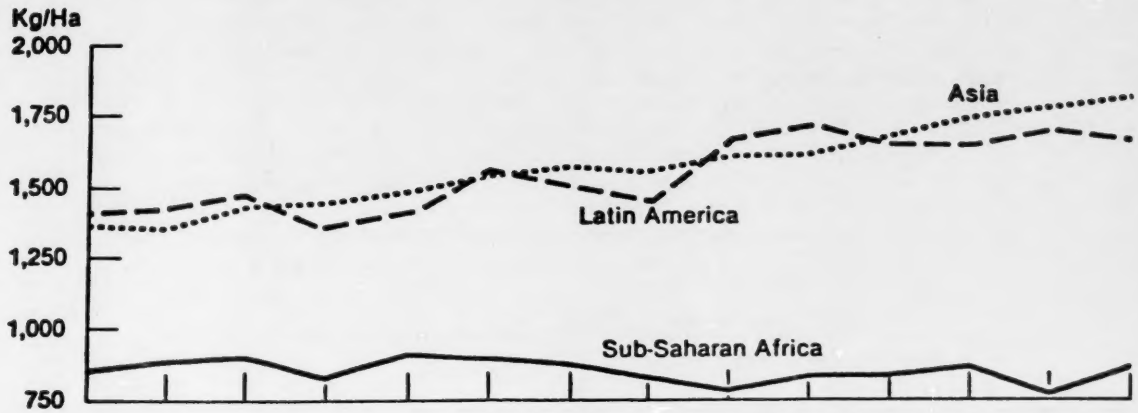


Table 1

Average annual growth rates in staple food production, yields and crop area, Sub-Saharan Africa, 1962/64-1972/74

Commodity and region	Production	Yield	Area
		Percent	
Cereal:			
Sahel	-1.6	-1.3	-0.3
West Africa	.7	- .6	1.3
Central Africa	3.2	-1.6	4.7
East and Southern Africa	2.6	1.5	1.1
Roots and tubers:			
Sahel	- .7	-1.2	.5
West Africa	1.8	.4	1.4
Central Africa	1.4	-1.7	3.1
East and Southern Africa	1.7	3.3	-1.5
Pulses:			
Sahel	1.6	-1.9	3.5
West Africa	2.0	-2.6	4.8
Central Africa	1.9	-2.0	4.0
East and Southern Africa	1.9	- .2	2.1

Source: Food and Agriculture Organization, Regional Food Plan for Africa, July 1978.

Most food production takes place in the subsistence sector. While land tenure patterns vary from region to region, farmers generally cultivate relatively small holdings. Cultivation practices are land-extensive; rotation, and various elaborate cropping patterns are major ways of managing the natural environment and maintaining soil fertility. African agriculture in general and food production in particular make less use of modern commercial inputs than cultivation in any other region of the world. Fertilizer use is lower than in either Asia or Latin America (Table 2), and there is much less systematic water control; Africa has less than one-twentieth the irrigated land of Asia. The development of improved seeds and higher yielding varieties lags far behind accomplishments in other developing nations.

Table 2

Modern input use, Africa, Asia, and South America, 1977

Area	Percentage of irrigated land	Tractors per 10,000 hectares	Fertilizer used per hectare
	Percent	Number	Kilograms
Africa	1.8	7	4.4
Asia	28.0	45	45.4
South America	6.1	57	38.8

Source: Food and Agriculture Organization, Production Yearbook, and Fertilizer Yearbook, 1978.

Basic foodstuffs are produced in large part by human labor, using simple hand tools like the hoe or the panga. The use of draft animals is more limited than in Asia, sometimes because of disease patterns in areas where the tse-tse fly is found, sometimes for cultural or economic reasons. Mechanization is used even less; Africa has less than one-sixth the number of tractors per hectare in Asia and one-eighth the number in Latin America (Table 2). With little water control and few ways of dramatically increasing the amount of work which can be done in a short time, food production is vulnerable to changes in weather and variations in the timing of key seasonal activities. This vulnerability is reflected in large variations in yields and in total production.

Many of the cultivation practices developed by African food producers were sound adaptations to their existing natural environment; one cannot attribute lower levels of commercial inputs to sheer backwardness. The natural resource base in much of Africa is quite different from that in temperate climates. Soils are more fragile, and the need to protect them from direct exposure to sun and rain led to different styles of cultivation. Rainfall patterns determine the timing of soil preparation in areas where the ground is too hard to till until rain falls. The need to maintain fertility in delicate soils led to the perfection of complex rotation and fallow systems. Nevertheless, these cultivation practices are beginning to reach their limits. The problem is not that land is, in general, scarce. On the contrary, Africa has more arable and permanent cropland than any other developing region--about 0.5 hectares per person. However, the population is not evenly distributed. Where there are major concentrations of people--as along the coast in West Africa or in the East African highlands--there is local population pressure. More important, the land in many areas is becoming scarce relative to the requirements of the prevalent land-extensive cultivation methods. Shorter fallow periods which degrade soil quality over time, and the excessive use of marginal land, are two examples of the pressure of growing land scarcity on the environment.

Over the decade of the 1980s, there will be a growing need to make a transition from land-extensive cultivation performed with hand tools to types of cultivation which can use appropriate inputs to enhance soil fertility, and can increase the efficiency of labor. Unless viable means of producing food this way can be found, increases in productivity cannot be achieved. However, such changes cannot spread far without a wider move toward more commercialized food production, supported by marketing infrastructure and policy.

Inadequate food production cannot be attributed solely to the food production sector. Two other factors loom large: the historical context within which food production occurs, and the government policies which influence food production and distribution.

Historical context. The structure of African agriculture has been heavily shaped by colonial policies designed to integrate colonies into metropolitan trading networks, and sometimes to protect settler populations. Taxation policy was instrumental in stimulating the production of agricultural exports (West Africa), as well as in providing a labor force for mining or plantation production (Southern and Central Africa), or working on settler-operated farms (Eastern and Southern Africa). Trade patterns, and the interest of European settlers, shaped the development of land tenure systems, infrastructure and commercial relations, agricultural technology, market access, and the direction of agricultural research. Several common themes emerged: African food production became a primarily subsistence activity, even in areas where substantial trade in foodstuffs existed before colonialism. Second, male partici-

pation in the off-farm work force or in cash crop cultivation frequently made women more responsible for food production. Third, lack of colonial interest in African food production meant little sustained research on food production, and hence, a relatively poor understanding of African production processes; recommendations for change were frequently counter-productive. Research on export crops was more extensive, and generally more productive.

While the historical dimensions are complex, three regional patterns can be discerned. In much of West Africa there were neither known deposits of minerals nor settler colonization. Policies were therefore directed at creating tropical agricultural exports, produced by African farmers themselves; costs of production were kept low enough to eliminate substitutes being developed within European markets. The coastal areas were linked directly with external markets, while the hinterland served as a pool of labor for the coast. In areas where land and labor were abundant, food crops were grown for domestic consumption along with the commercial export crops. Africans were frequently entrepreneurial-cultivators--using "traditional" ties to increase export crop production. In other areas, however, introducing export crops dislocated subsistence food production. The marketing of export crops here, as in other regions, was generally handled by non-Africans, while the commercialization of food marketing was limited.

In Central Africa, the production of agricultural export crops was generally managed by European concessionary companies. Industrial plantations for producing export crops were established directly by European investors, and worked by coerced or cheap labor. The African role in the commercial export crop was thus more limited. African food production remained largely a subsistence activity.

In Eastern and Southern Africa, colonial policy toward the agricultural sector was shaped by two forces: the labor requirements of mining, and the presence of large settler populations. A major thrust of colonial policy was to create labor reserves, both for mining and for working settler-operated farms. The need to feed miners--often migrants from distant areas--created a potential for a commercial market in foodstuffs, and initially this market was served by African producers. Later, however, restrictions on land ownership and production reduced the role of African producers, and commercial procurement came primarily from larger white-owned farms whose market position was supported by a wide range of government policies. The result was a dual land tenure system which had a major, negative impact on African food production.

This historical legacy affects food production today, as the trade patterns shaped by colonialism have not been fundamentally changed. Few countries have been able to significantly diversify their exports, or

move away from primary export to more highly processed goods. Agricultural policies designed to support the export activities which dominated African economies at independence are still in force, and these provide much of their foreign exchange and tax revenue. African governments have given food production relatively low priority, and the historical legacy is clearly apparent in the lack of infrastructure for effectively procuring and marketing locally produced foodstuffs.

Rural conditions and government policies. Goods and services found in urban areas are not generally available in rural areas. Higher prices for agricultural products would not stimulate more production if the consumer goods which people want to buy are unavailable. In addition, more personal income would not enable rural residents to purchase important services where the infrastructure needed to provide them is not present and cannot be financed through individual expenditures. Such services include hospitals, schools, safe drinking water, electricity, and decent roads. The net effect is to make the life which might be achieved in rural areas no comparison with the life in urban areas.

Neither does the education system place much emphasis on agriculture. Information and skills which might improve agricultural practices are not taught. The general orientation of education implies that farming is not a job for educated people. Hence, upward mobility is associated with high-status non-agricultural jobs in urban areas.

The general rural conditions, coupled with the physical drudgery of farming and the dominant orientation of educational systems, have several consequences. The younger more ambitious people migrate from rural areas, leaving agriculture to older less educated people. In some countries, such migration is now creating a shortage of rural labor; farming is not considered a career, and lacks prestige. Incentives to invest in improving food production are very weak. Instead, money made in agriculture is likely to be invested in other activities --ranging from education designed to assure that some family member can move out of agriculture to the purchase of small shops or a stock of goods for petty trading.

Government policies have also contributed to the poor food production record in Sub-Saharan Africa. Virtually all governments intervene in the production and marketing of food, and relevant policies often tend to derived from urban considerations--that is, the intended beneficiaries of the policies are groups other than the producers. The dominant thrust of most food policies, at least until the early seventies, was to keep domestic food prices low to benefit urban consumers. Farm prices were often set at low levels, and this discouraged farmers from marketing more food through official channels and reduced their incentive to invest in making food production a commercial enterprise. Trade

regulations were also oriented toward supplying urban consumers with cheap food, not with supporting farm income or attempting to build a strong internal marketing for domestically produced food (as is the case in many industrial countries). While government-controlled marketing institutions were designed in some cases to eliminate the unsavory actions of middlemen, they also had a strong interest in controlling procurement while keeping costs down. Compulsory procurement requirements, and attempts by some governments to operate state farms, were shaped by the need to procure for the urban market. Any policies oriented toward increasing food production and productivity would have required additional objectives and different policy instruments. These would include promoting change in agricultural practices by building effective rural institutions and adequate transportation and marketing networks, and providing appropriate social and economic incentives for their use through supportive price, credit and input policies.

In the aftermath of the food crisis of the early seventies, most African countries are attempting to become self-sufficient in key food crops. This interest has been reflected in the rhetoric and content of national plans, as well as in statements at international forums. The African members of FAO requested an assessment of what would be required to achieve food self-sufficiency by 1990. The first Organization for African Unity (OAU) economic summit, held in May 1980, placed increased food self-sufficiency high on its agenda. Many countries have responded positively to offers from FAO and the World Food Council to arrange for assistance with studies of their agricultural sector. Nevertheless, performance in the agricultural sector to date has lagged behind the rhetoric.

Improving food production will require more than organizing new production campaigns or removing past disincentives to production such as low producer prices. A whole range of policies--governing pricing, procurement, trade, storage, inputs, credit and investment--interact in important ways. If there are major inconsistencies among key aspects of these policies, the effect of one "correct" policy could be overshadowed by the negative impact of other policies, or of the constraints on policy implementation generated by the conflicting policies themselves.

The Nature of Demand

The diets of Sub-Saharan Africa are dominated by the consumption of roots, tubers, and cereals (Table 3). In virtually every country, these items in some combination provide more than 50 percent of daily calorie consumption. In the Sahel, diets are heavily cereal-based, featuring millet. In the more humid regions of West Africa, roots and tubers are important, sometimes overshadowing cereals. Some Central African countries such as Zaire have diets heavily based on cassava, with cereal consumption primarily in cities. Even in countries with relatively high

Table 3

Calories from cereals, roots, tubers and plantains, Sub-Saharan Africa

Country	Percentage of daily per capita caloric intake from: (daily average 1972-74)		
	Cereal	Roots, tubers and plantains	Total
	Percent		
Sahel:			
Cape Verde	56.3	7.0	63.3
Chad	66.0	3.4	69.4
Gambia	63.5	1.8	65.3
Mali	76.0	1.9	77.9
Mauritania	55.2	-	55.2
Niger	70.0	-	70.0
Senegal	62.6	3.9	66.5
Upper Volta	73.7	2.5	76.2
West Africa:			
Benin	41.6	32.0	76.3
Cameroon	36.6	31.4	68.0
Ghana	28.8	45.3	74.1
Guinea	59.1	20.9	80.0
Guinea-Bissau	50.5	19.4	69.9
Ivory Coast	35.7	40.6	76.3
Liberia	45.9	32.3	78.2
Nigeria	41.4	36.8	78.2
Sierra Leone	56.0	15.5	71.5
Togo	42.7	36.5	79.2
Central Africa:			
Angola	32.0	37.2	69.2
Central African Republic	22.9	52.9	75.8
Congo	12.6	65.7	78.3
Gabon	6.4	67.9	74.3
Zaire	16.1	60.8	76.9
East Africa			
Burundi	26.5	43.6	70.1
Ethiopia	70.6	3.0	73.0
Kenya	57.3	11.6	68.9
Rwanda 1/	18.5	56.5	75.0
Somalia	55.0	2.1	57.1
Sudan	47.3	10.6	57.9
Tanzania	33.9	30.3	64.2
Uganda 2/	29.8	31.5	61.3
Southern Africa:			
Botswana	59.6	-	59.6
Lesotho	53.2	-	53.2
Madagascar	64.4	16.6	81.0
Malawi	76.2	1.9	78.1
Mozambique	35.3	38.9	74.15
Namibia	46.1	14.4	60.5
Swaziland	58.1	2.3	60.4
Zambia	67.9	5.5	73.4
Zimbabwe	67.8	5.0	73.28

- = Value less than one percent

1/ Plaintains make up 30% of caloric intake.

2/ Plaintains make up 15% of caloric intake.

Source: Food and Agriculture Organization, Provisional Food Balance Sheets, 1972-74 Average.

concentrations of nomadic people (for example, Somalia) or important cattle operations (for example, Botswana), the bulk of the national diet is still derived from cereals amd/or roots and tubers. There are clear urban-rural differences in diet. Wheat as a complementary food (in the form of bread), and rice as a staple, are becoming increasingly important in urban areas, often displacing the traditional food.

Conclusions

Sub-Saharan Africa's precarious food balance stems from a combination of demand and supply factors. Urbanization and income growth have interacted with one another to create a structure of demand in urban areas that is difficult to match from domestic production, resulting in imports on an increasingly costly scale. While many African governments have spoken hopefully of reducing their food imports, particularly of wheat and rice, there is obviously a limited potential for doing so without risking political retribution. In this situation, governments have two other options: first, attempting to shift tastes and preferences of urban consumers away from imported foods and in the direction of domestically-produced foods through information campaigns and other measures; and second, attempting to make domestically-produced foods more palatable and convenient to urban dwellers through improved processing techniques. The first of these options would appear to be more applicable in the Sahel and East Africa, where strong tastes for imported food staples have developed. The second would appear to apply particularly to RTP (roots, tubers and plantains) in West Africa, for which our research indicates that an income preference exists.

Despite rural-urban migration, the increase of urban demand for food from domestic rural producers has been very weak because governments have hitherto been able to rely on imports to fill major urban demand from cities on coasts and waterways. Thus, the rural producing areas have been effectively isolated from linkage effects that in other parts of the world have resulted in self-sustaining agricultural development. So the subsistence sector, which accounts for the great bulk of food production in most parts of Africa, remains largely a closed one, responding mainly to the food needs of immediate local populations. Cash crops (for export) and off-farm labor earnings can provide ready cash as needed. Current methods leave farmers with a high degree of vulnerability to natural hazards from year to year. Moreover, the difficulties of transportation almost everywhere, together with the concentration of food production in brief growing periods in the semi-arid areas, result in wide seasonal price fluctuations in local markets and give rise to profit-making by traders and hoarders.

Citing the undesirable effects of speculation in the food trade, governments have intervened in staple food markets by setting procurement prices, attempting to enforce monopoly procurement, and creating barriers to the free movement of foods. The result has frequently been

to aggravate regional imbalances of food, and to exaggerate price instability. Costs to governments in these operations are high. Costs to producers are high as well; many producers are selling at harvest time only in order to pay off debts, in the expectation of buying back later in the year so as to get through the "hungry" season.

This situation will have to be drastically changed if domestic food production is to be expected to play a larger role in meeting aggregate food needs of African countries. The generally low levels of productivity must be raised; that this is possible is shown by demonstrations of a high yield potential from additional inputs in the agricultural experiment stations.

Where the transportation infrastructure is at its most rudimentary, or where it has been allowed to deteriorate since independence as in the Central African countries, producers in aggregate have not exhibited price responsiveness. Here, it is obvious that marketing costs are exorbitant, and government efforts to raise producer prices will be ineffective as a means of stimulating output except when combined with other costly investments from national budgets. On the other hand, in countries with relatively well integrated marketing networks, producers of staples for which there exists a strong demand in urban areas (provincial towns as well as capitals), like rice in West Africa and in Madagascar and Mozambique, have been shown to be price-responsive. Consequently, government investments in irrigation infrastructure, or reduction of the fertilizer-rice price ratio, can bring about large changes in output--up to a doubling of output.

Assuming the existence of appropriate price incentives to producers, however, the African countries would still lack the physical and human resources to produce sufficient additional quantities of staples to replace the totality of their imports, even if maize, millet, and other African crops were completely substitutable for imported rice and wheat. An enormous expansion of cropped area would be required to fill the import gap under present conditions of production. And assuming that yield-increasing packages of new technology were available, the financial resources necessary to sustain such an increase in production would seem to be lacking--except possibly in Nigeria. In sum, some portion of the import gap can possibly be closed in the coming decade, but not the whole gap.

In this situation, no magic solution exists. Upgrading the productivity of the large-farming sector and raising that of the subsistence sector both pose problems to government. Any increase in productivity implies a heavier use of fertilizer, pesticides, and other purchased inputs; this runs the risk of creating a new dependence on foreign sources of supply to replace an old one. The logistical problems of delivering inputs to the subsistence sector in African countries are obviously much greater than delivering them to a relatively

few large farms. On the other hand, the environmental consequences of clearing land for large farms in the present condition of limited knowledge about effects on tropical soils may be costly as well. Moreover, government investments in large-scale farming in an effort to bypass the subsistence sector and achieve high growth rates of food production would inevitably leave in place an impoverished rural population outside the big farms, who would produce a never-ending stream of migrants to the cities.

Narrowing the food gap will require a combination of price incentives to producers and a workable procurement system with massive government investments in productive infrastructure, training and extension services, and an upgrading of research programs. Our research indicates that the priorities that should be given these investments would vary from region to region in accordance with resource endowments and agricultural structure.

Improving the productivity of resources in the subsistence sector implies a transformation of the subsistence sector itself, since labor and land, the main productive resources, are deeply embedded in the socio-economic framework in which production takes place. The transformation will necessarily be in the direction of a much more heavily commercialized structure. This must be initiated in an environment where markets are far from perfect, uncertainty prevails, and the prices farmers receive for their product have been notoriously low compared to prices at the next point of sale. Indeed, the tendency to revert to local autarky appears today whenever marketing links are disrupted by political unrest or sharp reversals of government agricultural policies. Such a transformation, however, can be done in several ways. In East Africa higher productivity of food production per hectare could allow farmers to allocate more land to the production of traditional cash crops, which would be desirable in situations where government policymakers see income generation in rural areas to be a useful goal in itself. A similar change in West Africa could well take the form of more land allocated to production of maize, a non-traditional cash crop in much of the region, for commercial sale. And in the Sahel, it might allow marginal land to be taken out of production altogether, or fallow periods to be lengthened.

The introduction of new technologies is a major means of raising the productivity of resources in food production. Initiating the research work required for the development of such new technologies should rank high on the list of priorities in all regions. Careful thought needs to be given to the design of research programs, however, so that they do not lead to unfulfilled promises--as they have in the past. The design needs to take into account the structure of African agriculture, notably its relative factor endowments, as well as the limiting characteristics of soils and crops. The technology needs to be relatively self-contained, and not dependent on a heavy supporting infrastructure. New crop varieties

whose performance improvement consists in reducing the variability of yields could have a significant impact on production. Better linkage between information on consumer preferences and research on new crop varieties is important; there may be ways to ease the tendency of people with higher incomes to shift away from traditional staples.

Bringing about the transition to a more commercialized system of food production in a way that will avoid creation of large unmarketable surpluses and other such man-made problems hinges greatly on the timing of government policies, and on the skill with which their implementation is handled. Relative prices may become more important as markets improve, as will the ability of marketing systems to handle a wide range of crops. This implies close coordination of storage and trade policies with production policies. Flexibility in input deliveries will certainly be important. Input subsidies may have a role to play at the early stage of the transition in shaping production patterns, generating rural income, and creating effective farmer demand. This means that input subsidies should be used by African governments in a different way than they are used at present, which is to increase production of export crops. Instead, they should be used to capture linkages within the rural production sector; given the present high costs of transportation and marketing, what may appear to be a high operating cost of subsidy to create food supply may actually be a net economic benefit by its stimulative effect. At a later stage of the transition the input subsidies, which are relatively expensive for governments to sustain, may be reduced or dropped altogether.

The development of agricultural processing industries is another way of generating income in rural areas and creating linkages to national economies which do not exist at present. The successful local processing of roots and tubers in Central African countries, for instance, would represent a real gain in transportation costs, and would meet a demand for a more convenient food in urban areas.

The following specific conclusions have been drawn from the analysis:

1. In the near term, the coordination of government policies in food production, marketing, and trade offers the best hope of meeting food needs in Sub-Saharan Africa. The timing of the application of these different policies will need to vary from one country to another. The extent to which realization of production potential depends on improvement in one factor (e.g., inputs in Kenya) will also vary among countries. A policy success in one country may have repercussions, beneficial or harmful, in neighboring countries.

2. Shifting urban consumer tastes, and introducing new processing technologies for foods to make them more palatable and convenient, afford some scope for replacing a portion of imports with domestic production. Programs along these lines will help toward self-sufficiency in food for some countries and generate employment in all countries. The servicing of urban markets can create valuable linkages to rural areas where none exist at present.

3. The transformation of the subsistence sector in ways that raise living standards and respect social values must be a long-term goal of African governments. Such a transformation must be based on improving productivity in food production, which can be expected to lead either directly or indirectly to higher rural income, and decreased drudgery of farmwork. Rural purchasing power in turn could induce an infusion of consumer goods into rural areas which would act as a further stimulus to higher productivity, breaking the isolation of the subsistence sector.

4. We have taken a time frame of 10 years in the present study. In the longer term, a solution of the food problem in Sub-Saharan Africa probably depends on basic investments in education and research. Policies and programs suggested above will be self-limiting unless they are backed up by appropriate local institutions. Educational institutions must develop ways of raising the presently low status of agriculture so as to upgrade the quality of people and methods in food production. Research institutions must find the answers to basic unanswered questions about the capability of soils and crops to sustain a highly productive agriculture. While such investments seem to have little short run payoff, they are essential for longer run progress.

[Extracted from Chapters 1 and 6 and Executive Summary of Food Problems and Prospects in Sub-Saharan Africa: The Decade of the 1980s, Foreign Agriculture Research Report No. 166, U.S. Department of Agriculture, August 1981.]

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